

IOWA STATE COLLEGE
JOURNAL OF SCIENCE

A Quarterly of Research



VOL. 23
1948-1949

PUBLISHED BY
THE IOWA STATE COLLEGE PRESS
PRESS BUILDING
AMES, IOWA

IOWA STATE COLLEGE

JOURNAL OF SCIENCE

Published on the first day of October, January, April, and July

EDITORIAL BOARD

CHAIRMAN, R. M. Hixon.

EDITOR-IN-CHIEF, W. H. Bragonier.

ASSISTANT EDITOR, Marshall Townsend.

CONSULTING EDITORS: E. A. Benbrook, F. E. Brown, E. S. Haber, H. M. Harris, Frank Kerekes, P. Mabel Nelson, Robert W. Orr, J. W. Woodrow.
From Sigma Xi: D. L. Holl, C. H. Werkman.

All manuscripts submitted should be addressed to W. H. Bragonier, Botany Hall, Iowa State College, Ames, Iowa.

All remittances should be addressed to The Iowa State College Press, Press Building, Ames, Iowa.

Single Copies: \$1.25 (Except Vol. XVII, No. 4—\$2.00). Annual Subscription: \$4.00; in Canada \$4.25; Foreign \$4.50.

Entered as second-class matter January 16, 1935, at the post office at Ames, Iowa, under the act of March 3, 1879.

Vol. 23, No. 1, October, 1948

Abstracts of doctoral theses.	1
Note on an invariant of commutative algebras.	B. VINOGRAD 101
Aquatic and shore vegetation of Spirit Lake, Dickinson County, Iowa.	WILLIAM F. SIGLER 103
Seed characters of common clovers (<i>Trifolium</i>).	DUANE ISELY 125

Vol. 23, No. 2, January, 1949

Flora of Alaska and adjacent parts of Canada. VII.	J. P. ANDERSON 137
Report on thirty-five drugs and three plant materials tested against <i>Plasmodium lophurae</i> in the White Pekin duck.	ELERY R. BECKER 189
Life history and management of the yellow pikeperch, <i>Stizostedion</i> <i>v. vitreum</i> (Mitchill), of Clear Lake, Iowa.	ROBERT E. CLEARY 195
The use of vertebrae as indicators of the age of the northern black bullhead <i>Ameiurus m. melas</i> (Rafinesque).	WILLIAM M. LEWIS 209
Fermentative utilization of cassava. The production of ethanol.	JULIAN BANZON, E. I. FULMER, AND L. A. UNDERKOFER 219

Vol. 23, No. 3, April, 1949

The post-crisis in blood-induced <i>Plasmodium lophurae</i> infections in White Pekin ducks.	ELERY R. BECKER, CHARLES E. BRODINE, AND BONNIE L. CLAPPISON 237
Report on European corn borer resistance investigations.	S. D. BECK AND J. H. LILLY 249
Second supplementary list of parasitic fungi from Iowa.	J. C. GILMAN 261
The presence of water in oxygen-carrying cobalt compounds.	HARVEY DIEHL AND JOHANNA HENN 273
The reaction of ferrous iron with nioxime.	JOHN MATHEWS, JR. AND HARVEY DIEHL 279
An improved high frequency conductimetric titration apparatus.	ROBERT J. BEVER, CARL E. CROUTHAMEL, AND HARVEY DIEHL 289
The rate of precipitation of barium sulfate.	FREDERICK R. DUKE, ROBERT J. BEVER, AND HARVEY DIEHL 297

Vol. 23, No. 4, July, 1949

Histological development of "accessory blade" and associated abnormalities in maize.	JOHN E. SASS AND G. F. SPRAGUE	301
Life history of the white bass in Storm Lake, Iowa.	WILLIAM F. SIGLER	311
The warmouth, <i>Chaenobryttus coronarius</i> (Bartram), in Red Haw Hill Reservoir, Iowa.	WILLIAM M. LEWIS AND THOMAS S. ENGLISH	317
Influence of normal and immune duck plasmas on chick infections of <i>Plasmodium lophurae</i> induced with parasites in duck erythrocytes.	ELERY R. BECKER, CHARLES E. BRODINE, ALICE A. MAROUSEK, AND DORWIN A. BYRD	323
Growth and food habit studies of smallmouth black bass in some Iowa streams.	WILLIAM HAROLD TATE	343
Fisheries investigations on two artificial lakes in southern Iowa. I. Limnology and vegetation.	WILLIAM M. LEWIS	355
The bionomics of <i>Dermestes maculatus</i> Deg.: I. Oviposition, longevity, period of incubation.	JOHN K. SCOGGIN AND OSCAR E. TAUBER	363
Center of flexure of beams of triangular section.	R. N. GOSS	375
Torsion of composite sections.	L. E. PAYNE	381
Stress distribution due to hydrostatic pressure on a parabolic boundary.	KARL LEROY CONRAD	397

ABSTRACTS OF DOCTORAL THESES ¹

CONTENTS

An evaluation of certain agronomic and disease characters in advanced generations of bulk hybrid oat populations.	
	RICHARD ELTON ATKINS 3
The characterization and evaluation of drought hazard in Iowa.	
	GERALD L. BARGER 4
Flow of viscous fluid between slowly rotating eccentric cylinders.	
	JAMES W. BEACH 7
Some substitution reactions of organosilicon compounds.	
	ROBERT ANTHONY BENKESER 11
Soil moisture tension and microbiological activity.	
	HARI DAS BHAUMIK 13
Some factors affecting nitrogen transformations and organic matter decomposition in soils.	
	FRANCIS E. BROADBENT 16
Separation of cadmium from zinc by controlled cathode potential electrodeposition.	
	RICHARD J. BROUNS 18
Production and some reactions of furfuryl alcohol.	
	HORACE D. BROWN 20
Effect of freezing on tenderness and on ice crystal formation in poultry after various periods of aging.	
	MARY AGNES FRANCES CARLIN 23
Dihydroxyphenylalanine metabolism by kidney tissue.	
	ROBERT EDWARD CLEGG 25
Radio-frequency radiation from electric discharges in gases.	
	WILLIS LAURENS EMERY 27
Life history and ecology of the canvas-back, <i>Nyroca valisineria</i> (Wilson), in southeastern Oregon.	
	RAY CHARLES ERICKSON 30
Inheritance of protein, zein, tryptophan, valine, leucine, and isoleucine in two maize hybrids.	
	KENNETH JOHN FREY 33
Histological, physical, and organoleptic changes in three grades of beef during aging.	
	DOROTHY LUCILE HARRISON 36
The inheritance of agronomic characters in barley.	
	ERHARDT R. HEHN 39
Commercial extraction of soybean oil using non-inflammable solvents.	
	EUGENE GRAHAM HOLLOWELL 41
The morphology and genesis of prairie soils developed from Peorian loess in southwestern Iowa.	
	CURTIS EVAN HUTTON 44
A comparison involving the numbers of, and relationship between testers in evaluating inbred lines of maize.	
	KENNETH R. KELLER 46

¹ Complete copies of these theses may be consulted at the Library, Iowa State College, Ames, Iowa.

Polygenic inheritance of fruit size in red pepper (<i>Capsicum frutescens</i> L.).	IAN KHAMBANONDA	48
Properties of kernels of integral equations whose iterates satisfy linear relations.	CARL ERIC LANGENHOP	50
Stratification in survey sampling.	CLIFFORD JOSEPH MALONEY	53
Soluble manganese as a factor affecting the growth of various legumes in culture solutions and in acid soils.	HAROLD DONALD MORRIS	55
Orientation and cleavage of some substituted dibenzothiophenes.	JOHN FRANCIS NOBIS	57
Bacterial metabolism of glycine and alanine.	DAVID PARETSKY	61
The physiological action of thiamine analogues in thiamine dependent systems.	JOSEPH C. PICKEN, JR.	64
Substituted pyridine and quinoline sulfides.	MARY ALYS PLUNKETT	67
Avian responses to cover-water interspersions in marshes of Clay and Palo Alto counties, Iowa.	MAURICE W. PROVOST	69
Collagen and elastin content of four beef muscles aged varying periods of time.	INEZ PRUDENT	72
Viability and vigor of inbred and hybrid maize seed subjected to freezing temperatures.	ELMER C. ROSSMAN	75
Toxicity of azobenzene and certain related compounds to insects.	SILAS S. SHARP	78
Potassium fixation in soils as affected by type of clay mineral, moisture conditions, and concentration of other ions.	GEORGE STANFORD	80
An ecological study of the minnows of the Des Moines River, Boone County, Iowa.	WILLIAM CHARLES STARRETT	83
Photoperiodic responses of maize.	ROBERT O. THOMAS	86
Inheritance and interrelation of some agronomic and chemical characters in an interspecific cross in soybeans, <i>Glycine max</i> × <i>G. ussuriensis</i> .	CHARLES ROBERT WEBER	89
Fat metabolism in yeast.	ALAN G. C. WHITE	91
The preparation and reactions of the chloromethyl ether of 2,3-butanediol monoacetate.	ERNEST L. WIMMER	94
Host-parasite relationship of <i>Chalara quercina</i> and species of quercus.	ROY A. YOUNG	97

AN EVALUATION OF CERTAIN AGRONOMIC AND DISEASE CHARACTERS IN ADVANCED GENERATIONS OF BULK HYBRID OAT POPULATIONS¹

RICHARD ELTON ATKINS

From the Department of Agronomy, Iowa State College

Segregates from the F_3 , F_7 , and F_8 generations of bulk hybrid oat populations were tested in the greenhouse for reaction to specific races of crown and stem rust and for reaction to *Helminthosporium victoriae*. Bulk F_7 and F_8 populations of ten oat crosses and fifty segregates from each bulk population were grown in the field and evaluated for yield, date of heading, date of maturity, and plant height.

The forces of natural selection were very effective in increasing the proportion of disease resistant types in advanced generations of bulk populations. The intensity of such selection was proportional to the prevalence and severity of infection of the specific diseases.

Bulk populations which gave the highest yields in replicated tests in the early segregating generations did not produce the greatest proportion of high yielding segregates in subsequent generations. These results suggest that considerable high yielding germ plasm may be lost if bulk crosses are discarded on the basis of early generation yield performance. No association was evident between heading date, maturity or plant height of segregates from bulk populations, and the previous yield performance of the bulk population.

Correlations between successive generations for yield of bulk hybrid populations were consistently low. Predictions of yield performance of bulk hybrids from their performance in previous generations appear to be of limited value. Bushel weight was highly correlated in successive generations and valid conclusions may be drawn from bushel weights obtained in early generations.

The extent of difference in yield, maturity, and plant height of parental varieties involved in a cross was of no value in predicting the range obtained from these characters in a random group of segregates from a bulk population of that cross.

¹ Doctoral thesis number 891, submitted March 15, 1948.

THE CHARACTERIZATION AND EVALUATION OF DROUGHT HAZARD IN IOWA¹

GERALD L. BARGER

From the Department of Agronomy, Iowa State College

Methods for characterizing drought intensity and for estimating the frequency of droughts of certain intensities have been developed. Estimates of the minimum amounts of rainfall required by the corn crop during time intervals of n consecutive standard weeks, where $1 \leq n \leq 16$, have been determined. (Standard climatological weeks are numbered 1 through 52 beginning with March 1-7 as the first week.) The fitting of curves to the frequency distributions of n week rainfall totals has afforded a means of evaluating the drought hazard for a given soil association area in Iowa in terms of probability of occurrence.

Analysis of rainfall records for six stations—Fayette, Rock Rapids, Ames, Clarinda, Corydon, and Fairfield—has been completed. Average annual corn yields for the counties in which the stations are located were used to define the base amounts of rainfall required for an average corn crop in each county. These base amounts, for periods of one to sixteen weeks at each station, are shown in Table 1. Any n week period during the corn growing season (beginning May 17 and ending September 5), which shows a total precipitation amount less than the base amount for the corresponding value of n in Table 1, experiences a rainfall deficit or drought. The largest such deficit for one season, regardless of the length of period observed, is correlated rather closely with corn yield. In fact, 25 to 60 per cent of all variation in average county corn yields of these six counties, for the years in which drouth occurred, is explained by this maximum rainfall deficit alone.

With the above indication that the measure of drought intensity adopted does have some significance with relation to Iowa agricultural production, a method was devised for estimating the likelihood of occurrence of drought at each station studied. The frequency distribution of n week rainfall totals is bounded at zero and tails out to the right, particularly when n is small; i.e., for short periods of time. The incomplete gamma distribution shown in the equation proved a good fit for these positively skewed distributions. With the origin at zero this incomplete gamma distribution takes the form

$$y = \frac{N(\gamma)}{\Gamma(p)} e^{-\gamma x} x^{p-1}$$

where N is the total frequency, x is the n week rainfall total in inches, and p and γ are parameters estimated by maximum likelihood approximations which are jointly sufficient.

¹ Doctoral thesis number 907, submitted June 7, 1948.

From this equation the probability of receiving less than the base amount of rainfall, x_d , during a run of n weeks beginning with a certain week m , was computed with the aid of a set of tables of the incomplete Γ -function. Table 2 gives the probabilities associated with droughts of varying length beginning with week number 12 (May 17-23) at each station. Similar computations were completed for other dates of beginning throughout the season, and by interpolation the probability of ex-

TABLE 1
MINIMUM REQUIRED n WEEK RAINFALL (INCHES)

Station						
n	Rock Rapids	Fayette	Ames	Clarinda	Corydon	Fairfield
1.....	....*	....	....	....	....	....
2.....	....	0.13	....	0.19	0.24	....
3.....	0.30	0.42	0.32	0.68	0.75	0.43
4.....	0.74	0.80	0.71	1.20	1.31	0.96
5.....	1.22	1.28	1.14	1.74	1.92	1.55
6.....	1.72	1.85	1.61	2.30	2.59	2.21
7.....	2.26	2.52	2.13	2.89	3.32	2.92
8.....	2.83	3.28	2.68	3.50	4.10	3.71
9.....	3.43	4.15	3.27	4.13	4.94	4.55
10.....	4.07	5.10	3.90	4.79	5.83	5.45
11.....	4.73	6.15	4.58	5.48	6.78	6.42
12.....	5.43	7.30	5.29	6.17	7.79	7.45
13.....	6.16	8.54	6.05	6.92	8.85	8.55
14.....	6.93	9.88	6.84	7.67	9.96	9.70
15.....	7.72	11.32	7.68	8.45	11.14	10.92
16.....	8.55	12.85	8.56	9.26	12.36	12.20

*Negative amounts from regression omitted.

periencing less than x_d inches of rainfall during any n week period beginning during the growing season could be estimated. Similarly, the probability of rainfall in any given class interval could be calculated. The uses of the distribution function are by no means limited to this drought study. Likelihood of excessive rainfall could be found just as readily.

Table 1 indicates some rather definite differences between bases for various stations. The differences between Rock Rapids and Fayette, Fayette and Corydon, Ames and Clarinda, Ames and Corydon, Clarinda and Corydon, and Clarinda and Fairfield did prove statistically significant. However, the same bases might well be used for Rock Rapids and Ames and another for Corydon and Fairfield. The probability of drought, of course, combines the rainfall contingency at a station with the drought base characteristic of that area, so the relationship between stations is somewhat modified in Table 2. Table 1 shows how much rainfall is needed for an average corn crop in each county; Table 2 gives the probability of getting this amount or less.

In general, Corydon and Fairfield represent the most susceptible portion of the state from the standpoint of drought hazard. Since these areas get as much or more rain than most of the other stations, this high contingency for drought must be due to the high base amounts needed in these two sections. Probably these high requirements are occasioned chiefly by soil characteristics, though some differences in evaporation conditions may be influential. The latter conditions must be the object

TABLE 2
ESTIMATED DROUGHT PROBABILITIES*

Station						
<i>n</i>	Rock Rapids	Fayette	Ames	Clarinda	Corydon	Fairfield
1.....	0.00	0.00	0.00	0.00	0.00	0.00
2.....	0.00	0.03	0.00	0.01	0.03	0.00
3.....	0.04	0.02	0.01	0.04	0.06	0.02
4.....	0.04	0.02	0.02	0.04	0.07	0.03
5.....	0.04	0.02	0.02	0.05	0.09	0.05
6.....	0.04	0.02	0.03	0.06	0.10	0.06
7.....	0.04	0.03	0.03	0.06	0.12	0.08
8.....	0.05	0.03	0.04	0.06	0.14	0.10
9.....	0.05	0.05	0.04	0.06	0.16	0.12
10.....	0.06	0.06	0.05	0.07	0.19	0.14
11.....	0.07	0.08	0.05	0.09	0.23	0.17
12.....	0.08	0.11	0.06	0.08	0.25	0.18
13.....	0.08	0.15	0.07	0.08	0.29	0.21
14.....	0.09	0.18	0.08	0.08	0.31	0.25
15.....	0.11	0.24	0.09	0.10	0.34	0.29
16.....	0.13	0.32	0.10	0.10	0.36	0.33

* $m = 12$

of some detailed study before their effects can be evaluated accurately. It is thought that the tight, impermeable nature of the B horizon in most of the Grundy, Shelby, Seymour, and especially Edina soil types in southern Iowa limits moisture intake and plant root growth to such an extent that the available water supply at any one time is rather small and must be replenished at relatively short intervals of time.

The western counties have a greater probability of drought occurrence than the central and eastern areas, but here the rainfall distribution itself is a factor. Fayette, for example, enjoys a more bountiful supply of summer rainfall than does Rock Rapids and consequently is less likely to suffer drought, even though the requirements are greater around Fayette than in the Rock Rapids vicinity.

The analysis of data for several more stations is contemplated, and it is hoped that tables of probabilities for useful ranges of p , γ , and \bar{x} will be compiled before this phase of the study is completed. Such tables would make it possible to read directly the probability of occurrence of rainfall amounts in a desired class interval, once the estimates of the three parameters in the equation had been computed.

FLOW OF VISCOUS FLUID BETWEEN SLOWLY ROTATING ECCENTRIC CYLINDERS¹

JAMES W. BEACH

From the Department of Mathematics, Iowa State College

This paper deals with the problem of the slow, steady motion of an incompressible, viscous fluid between two eccentric, rotating, infinitely long cylinders whose axes are vertical. The fluid is subject to the restrictions necessary to obtain

$$\Delta^4 \psi = 0 \quad (1)$$

as the differential equation for the flow of a fluid,² where ψ is the stream function. In addition, it is assumed that a viscous fluid adheres to the walls of the bounding cylinders which gives the boundary conditions

$$\begin{aligned} \text{on } q_1 \quad \psi(q_1) &= M_1 \text{ and } \frac{\partial \psi}{\partial n} = -2N_1 \\ \text{on } q_2 \quad \psi(q_2) &= M_2 \text{ and } \frac{\partial \psi}{\partial n} = -2N_2, \end{aligned} \quad (2)$$

where M_1 , M_2 , N_1 , and N_2 are constants, q_1 is the radius of the outer cylinder, and q_2 is the radius of the inner cylinder.

Any cross section perpendicular to the axes of the cylinders gives two eccentric circles. The x -axis is taken along their common diameter and the origin at the internal intersection point of the family of circles orthogonal to the eccentric circles. The centers of the bounding circles are at $(h_1, 0)$ and $(h_2, 0)$. The distance between the two points common to the orthogonal circles is the constant a . The general solution³ of equation (1) is

$$\psi(z, \bar{z}) = \Phi_0(z) + \overline{\Phi_0(z)} + \bar{z} \Theta_0(z) + z \overline{\Theta_0(z)},$$

where $\psi_0(z)$ and $\Theta_0(z)$ are analytic function of the complex variable $z = x + iy$ and the bar over a function indicates the conjugate function. This solution is transformed by the transformation

$$z = w(\alpha) = \frac{-a\alpha}{1 + \alpha} \quad \text{or} \quad \alpha = u + iv = \frac{-z}{a + z}, \quad (3)$$

¹ Doctoral thesis number 904, submitted June 5, 1948.

² Richard Von Mises, and Kurt O. Friedrichs, *Fluid Dynamics*. Brown University, Providence, R. I., 1941, p. 151.

³ I. S. Sokolnikoff, *Mathematical Theory of Elasticity*. Brown University, Providence, R. I., 1941, pp. 243-44.

M. Goursat, "Sur l'equation $\Delta \Delta u = 0$." *Bul. Soc. Math. de France*, 26:236. 1898.

which transforms the region between the eccentric circles to the region between concentric circles with radii r_1 and r_2 . The general solution transforms to

$$\psi(\alpha, \bar{\alpha}) = \Phi(\alpha) + \overline{\Phi(\alpha)} + \overline{w(\alpha)} \Theta(\alpha) + w(\alpha) \overline{\Theta(\alpha)}. \quad (4)$$

From physical considerations the stream function, ψ , is single-valued in the region as are its derivatives. To satisfy these conditions the functions $\Phi(\alpha)$ and $\Theta(\alpha)$ must have the following forms:

$$\Phi(\alpha) = \overline{H} w(\alpha) \ln \alpha + F \ln \alpha + \Phi_3(\alpha) \quad (5)$$

$$\Theta(\alpha) = H \ln \alpha + \Theta_3(\alpha).$$

H is a complex constant, F a real constant; $\Phi_3(\alpha)$ and $\Theta_3(\alpha)$ are single-valued functions. These functions, $\Phi_3(\alpha)$ and $\Theta_3(\alpha)$, are expressed as infinite series by a Laurent's expansion in $re^{i\theta}$ with undetermined coefficients.

Because the normal derivative of ψ is not readily expressed as an infinite series the directional derivative along the circles orthogonal to the bounding circles is used. This function is

$$-2 \frac{\partial \psi}{\partial z} \frac{\bar{z}}{z} e^{i\theta} \quad (6)$$

and is equal to the normal derivative at the boundary, so it is known on the boundary.

The functions (4) and (6) are both expressed in terms of (5) and then $\Phi_3(\alpha)$ and $\Theta_3(\alpha)$ expressed as infinite series. The values of r on the two circles are substituted into the result and these functions are then set equal to their values on the boundary. Like powers of $e^{i\theta}$ are equated. The infinite number of equations so obtained are solved for the unknown coefficients in the Laurent's series and also for H , \overline{H} , and F . The results are substituted into (4) giving the value of the stream function in the α -plane. This is then transformed to the z -plane. The final solution of the equation (1) under the conditions stated is

$$\begin{aligned}
 \psi(z, \bar{z}) = A \left\{ (-z - \bar{z} - a) \left[\ln \frac{z\bar{z}}{(a+z)(a+\bar{z})r_1^2} + \frac{(1-r_2^2)r_1^2}{r_1^2 - r_2^2} \right] \right. \\
 + z\bar{z} \frac{(1-r_1^2)(1-r_2^2)}{a(r_1^2 - r_2^2)} \left. \right\} + P \left\{ (r_1^2 - r_2^2) \left[\ln \frac{z\bar{z}}{(a+z)(a+\bar{z})r_1^2} \right. \right. \\
 + \frac{z+\bar{z}}{a} \left. \right] - \frac{r_1^2 r_2^2 (a+z)(a+\bar{z})}{a z \bar{z}} (z+\bar{z}) - \frac{z\bar{z}}{a(a+z)} - \frac{z\bar{z}}{a(a+\bar{z})} \\
 \left. + 2r_1^2 \right\} + M_1, \quad (7)
 \end{aligned}$$

where

$$\begin{aligned}
 A = - \frac{N_1 r_1 (1-r_2^2) - N_2 r_2 (1-r_1^2)}{1-r_1^2 r_2^2} + \frac{2P}{a} \frac{(1-r_1^2)(1-r_2^2)(r_1^2-r_2^2)}{1-r_1^2 r_2^2} \\
 P = \frac{M_1 - M_2}{2(r_2^2 - r_1^2) + (r_1^2 + r_2^2) \ln \frac{r_1^2}{r_2^2}}.
 \end{aligned}$$

It is shown that by taking the limiting value of this solution as the cylinders become concentric the solution for concentric rotating cylinders is obtained.

The solution (7) is used to obtain the torque and thrust on either cylinder. The torque is

$$T_k = 8\pi \mu \frac{-A}{r_1^2} (a + 2h_k) + P(r_1^2 + r_2^2), \quad k = 1 \text{ or } 2,$$

$\ln \frac{r_1^2}{r_2^2}$

where μ is the coefficient of viscosity. If $k = 1$, the torque on the outer cylinder is given while the value on the inner cylinder is given by setting $k = 2$. The thrust in the direction of the common diameter of the bound-

ing cylinders is zero and that normal to this direction, per unit height of the cylinders, is

$$F_y = 16\pi\mu \frac{A}{\ln \frac{r_1^2}{r_2^2}}.$$

These results are valid whether one cylinder is rotating or both.

The relationship between this problem in flow of fluid and the problem of deflection of a circular plate with an eccentric hole is discussed.

This paper presents the solution of the problem of the slow, steady flow of a viscous fluid between rotating, infinitely long, eccentric cylinders by a method not previously used on this problem. The torque and force on either cylinder are given and special cases are discussed presenting the effects of changing eccentricity or relative velocity of the bounding cylinders. All results are applicable whether one cylinder or both are rotating.

SOME SUBSTITUTION REACTIONS OF ORGANOSILICON COMPOUNDS¹

ROBERT ANTHONY BENKESER

From the Department of Chemistry, Iowa State College

Substitution reactions on organosilanes are usually complicated by a partial cleavage of the carbon-silicon bond since this bond is generally unstable in the presence of halogens or strong acids. Accordingly, it was the purpose of this thesis, in part, to study the optimum conditions for such reactions so as to establish them as possible synthetic tools for preparing new and biologically useful organosilicon compounds.

The following substitution reactions were successfully accomplished: triethyl-*p*-anisylsilane, b.p. 100°–103°/0.2 mm., was metalated with butyllithium to yield on carbonation triethyl-3-carboxy-4-methoxyphenylsilane, m.p. 52°–56°; triphenyl-2-thienylsilane was metalated with butyllithium to yield on carbonation presumably triphenyl-2-thienyl-5-carboxysilane, m.p. 188°–190°; trimethylphenylsilane was nitrated with fuming nitric acid (d. 1.5) to yield largely trimethyl-*p*-nitrophenylsilane, b.p. 82°–83°/0.7 mm. This nitro compound could be reduced with Raney nickel at 50 lbs. of hydrogen pressure to the amine, b.p. 66°–66.5°/0.7 mm.

The following substitution attempts were unsuccessful: the attempted bromination of trimethylphenylsilane resulted in cleavage of the trimethylsilyl group, and a 72 per cent yield of bromobenzene was obtained; there was no reaction between triethylphenylsilane and butyllithium; the attempted metalation of trimethyl-9-fluorylsilane, m.p. 97.5°–99.5°, with butyllithium resulted in cleavage, and only fluorene-9-carboxylic acid could be isolated.

The second portion of the thesis is concerned with the synthesis of potential antimalarials of the quinoline series, consisting of some quinolinemethanols, quinoline sulfides, and 7-chloroquinolines.

The quinolinemethanols were usually prepared by the reaction between 6-methoxy-2-phenylquinoline-4-aldehyde² and 6-methoxy-2-phenyl-4-quinolyl methyl ketone³ with the Grignard reagent of the appropriate halide. The compounds thus prepared were: α -methyl- α -phenyl-6-methoxy-2-phenyl-4-quinolinemethanol, m.p. 188°–188.5°; α , α -dimethyl-6-methoxy-2-phenyl-4-quinolinemethanol, m.p. 153.5°–155.5°; α -methyl-6-methoxy-2-phenyl-4-quinolinemethanol, m.p. 119°–120°; α -(3-diethylaminopropyl)-6-methoxy-2-phenyl-4-quinoline-methanol dihydrochloride, m.p. 238°–244°; α -(3-di-*n*-butylamino-propyl)-6-methoxy-2-phenyl-4-quinolinemethanol dihydrochloride, m.p. 200°–203°; α -(*o*-

¹ Doctoral thesis number 866, submitted August 12, 1947.

² Gilman, Marshall, and Robert Benkeser, *Jour. Amer. Chem. Soc.*, 68:1849 (1946).

³ Lutz, *et al.*, *Jour. Amer. Chem. Soc.*, 68:1813 (1946).

anisyl)-6-methoxy-2-phenyl-4-quinolinemethanol hydrochloride, m.p. 217°-220°.

The quinoline sulfides were usually prepared by treating the appropriate quinoline halide with sodium methyl mercaptide. When the halogen was not in the 2- or 4-position of quinoline it was activated by the presence of an adjacent nitro group. Some typical sulfides prepared were: 8-(3-diethylaminopropylamino)-6-quinolyl methyl sulfide dihydrochloride, m.p. 217°-220°; 8-nitro-7-quinolyl methyl sulfide, m.p. 157°-159°; 7-chloro-4-quinolyl methyl sulfide, m.p. 124°-125°.

The 7-chloroquinolines were prepared by the addition of the appropriate RLi^4 to the anil linkage of 4, 7-dichloroquinoline followed by a condensation with 3-diethylaminopropylamine. Some of the compounds thus prepared were: 2-*p*-methoxyphenyl-4, 7-dichloroquinoline, m.p. 121°-121.5°; 2-*p*-chlorophenyl-4, 7-dichloroquinoline, m.p. 166°-167°; 2-*p*-tolyl-4, 7-dichloroquinoline, m.p. 124°-125°; 2-*p*-methoxyphenyl-7-chloro-4-(3-diethylaminopropylamino) quinoline, m.p. 118°-119°; 2-*p*-chlorophenyl-7-chloro-4-(3-diethylaminopropylamino) quinoline, m.p. 127°-128°; 2-*p*-tolyl-7-chloro-4-(3-diethylaminopropylamino) quinoline, m.p. 119.5°-120.5°.

The thesis also contains a thorough literature review of the organic chemistry of silicon from 1927 to 1936 and some theoretical aspects of the experimental results are discussed.

⁴ Gilman and Benkeser, *ibid.*, 69:123 (1947).

SOIL MOISTURE TENSION AND MICROBIOLOGICAL ACTIVITY¹

HARI DAS BHAUMIK

From the Department of Agronomy, Iowa State College

Moisture is recognized to play an important role in the biological decomposition of complex organic materials in soil. There is a considerable lack of agreement among different workers as to the moisture content of the soil optimum for biological activity. Moisture contents in soil have been expressed in terms of percentage of oven dry soil, as percentage of maximum water-holding capacity, and as the thickness of moisture film around the soil particles. The present study has been carried out from the point of view of energy concept of soil moisture. The moisture content has been expressed in terms of the tension with which water is held by the soil.

Five Iowa soils differing in texture were incubated under standard conditions at moisture tensions of 3,160, 502, 50, 10, 1, and 0 centimeters of water in order to study the effect of soil moisture tension upon microbiological activity.

Moisture retaining capacities of Thurman fine sand, Clarion loam, Clarion fine sandy loam, Webster silt loam, and Wabash silty clay were determined. Moisture content at any given tension increased progressively for these soils in the order named. The carbon/nitrogen ratios of all soils were of similar order and suggested that their native organic matter was in an advanced stage of decomposition.

Rate of carbon dioxide evolution following addition of 1 per cent ground corn stover, mineralization of organic nitrogen following addition of 2 per cent egg albumin, and population changes in the soil microflora as revealed culturally were taken as criteria for microbiological activity.

Carbon dioxide evolved from experimental soil lots was collected continuously and was determined after 1, 2, 3, 4, 6, 9, 12, and 15 days. The moisture tension at which the maximum cumulative total amount of carbon dioxide was evolved during fifteen days differed for the several soils. No two soils showed total cumulative maxima at the same moisture tension. For all soils, however, the peak daily rate of carbon dioxide production was observed at or very near 50 cm. of moisture tension.

At a given moisture tension, the curves showing the relation between daily rates of carbon dioxide evolution and period of incubation were similarly shaped for all soils. At higher moisture tension there is a rapid increase in the rate of carbon dioxide evolution during the initial stages of incubation, and the early maximum is followed by a rapid decrease. The nature of the curve suggests a logarithmic ascent followed by a simi-

¹ Doctoral thesis number 882, submitted December 16, 1947.

lar descent, similar in characteristic to the growth curve of micro-organisms.

The shapes of the curves towards saturation are entirely different from those for the drier range. The sharp peak is absent and the curves are more or less flat. In most cases there are two peak rates, the first one being attained during the earlier stages of incubation (generally within two days) and the second one at approximately six to nine days. The second peak rate is entirely absent in the case of drier soils. The first peak rate is believed to be due to more specialized aerobic flora and the second one due to the development of a new flora, anaerobic or facultative in type.

In the unamended soils, the rate of biological decomposition of native organic matter appeared very slow. There was no linear relationship between the organic matter content and the amount of carbon dioxide evolved. Thurman sand showed the lowest and Clarion loam the highest quantity of carbon dioxide, when the five soils were incubated unamended. With added organic matter, Thurman sand showed the highest carbon dioxide evolution. These data indicated that the differences in the organic matter content of the original soil were of little or no importance in determining the amounts of carbon dioxide evolved on incubation.

Alteration of surface/volume ratio by use of differently shaped incubation containers led to differences in carbon dioxide evolution from wet soil. With comparatively dry soil, the surface/volume ratio appeared less important.

The rate and extent of carbon dioxide evolution from Webster silt loam was extremely slow when it was waterlogged to about 5 cm. above the soil surface due to a very low rate of diffusion of oxygen and creation of practically anaerobic conditions.

The influence upon carbon dioxide evolution of a radical shift in the moisture status of a soil while active decomposition was in progress was investigated in parallel experiments upon Thurman sand and Webster silt loam. When the soil moisture was changed abruptly from 50 cm. to 0 cm. of moisture tension, carbon dioxide evolution was reduced to a rate below that occurring in soil maintained at a constant water tension of 0 cm. In the following days of incubation, however, there was a gradual increase in the rate of carbon dioxide evolution, and the shape of the curves, showing relation between daily rates of carbon dioxide evolution and period of incubation, for soil initially at 0 cm. tension and for soil abruptly changed to that tension during incubation became roughly parallel.

Mineralization of egg albumin was studied in Thurman fine sand and in Wabash silty clay, with determinations of ammonia, and nitrite, and nitrate nitrogen being made after 1, 2, and 4 weeks. Differences in the rates of mineralization at differing moisture tensions were apparent only during the first week or two of incubation; they disappeared as the incubation period was continued to four weeks. Maximum rate of mineralization of nitrogen in both soils occurred at 50 cm. of moisture tension.

There was considerable loss of ammonia from the sandy soil due to

volatilization but there was little or no loss from the silty clay soil. Mineralization of organic nitrogen was more complete in Thurman sand than in Wabash silty clay at the end of four weeks of incubation.

Microbiological analyses by cultural methods revealed differences in the abundance of microbial groups, both at differing tensions of moisture within the same soil as well as among the several soils when maintained at the same moisture tension. It is believed that differences in microbial populations in soils are at least partly responsible for differences in the cumulative total amounts of carbon dioxide evolved from the several soils. Pure culture studies with bacteria, actinomycetes, and fungi in steam-sterilized Webster silt loam showed that the activity of fungi, as shown by carbon dioxide evolution, remained fairly constant within the range of moisture tensions employed. Carbon dioxide production by bacteria and actinomycetes was greatly depressed with increase in moisture tension. Microbial populations, however, were found to be greater in the drier soils.

SOME FACTORS AFFECTING NITROGEN TRANSFORMATIONS AND ORGANIC MATTER DECOMPOSITION IN SOILS¹

FRANCIS E. BROADBENT

From the Department of Agronomy, Iowa State College

In the decomposition of highly available energy materials such as sucrose in soil it was shown that a net loss in organic matter may occur. Sucrose, of course, represents an energy source more readily utilized by micro-organisms than any organic residue likely to find its way into soil, yet it is likely that the final result might often be the same with green manures over a longer time interval. Under some conditions green manures may decrease the soil organic matter rather than increase it.

Nitrogen mineralization experiments, some of which involved the use of N^{15} as a tracer, indicated that most nitrogen released after the addition of plant residues to soil is derived from the soil rather than from the added residues. Nitrogen release appeared to depend to some extent on the intensity of microbial activity, which involves loss of carbon and consequent reduction in the carbon nitrogen ratio. Rapid loss of carbon shortens the interval between the time when nitrogen is deficient, resulting in immobilization of any inorganic nitrogen which is present, and the time when nitrogen is present in excess, resulting in rapid ammonification. Where glucose was used as a source of available energy, this interval was shorter than where cellulose was used.

In an experiment with Sudan grass enriched with C^{13} and N^{15} it was shown that nitrogen release from the soil organic matter was accelerated to a greater extent than was decomposition of the organic matter as a whole. It is possible that a large part of the nitrogen supplied to succeeding crops by green manures has its origin in the supposedly stable soil organic matter rather than in the fresh plant residues. The nitrogen mineralized from the soil organic matter might be considered to be "displaced" by the nitrogen in plant proteins just beginning a series of complex transformations, the last of which is conversion to nitrate.

The relative rates of decomposition of plant materials in soil were found to be inversely related to the quantity added. Mathematical interpretation of the data showed that the decomposition of small amounts of straw in soil was essentially a first-order reaction during the first few days. The decomposition of larger amounts of plant material was generally less than would have been expected from a first order reaction. By using Sudan grass enriched with the C^{13} tracer it was shown that differences in relative decomposition rates were due in part to the lack of proportionate stimulation of soil organic matter decomposition by the added residues. These differences were also found to be affected by

¹ Doctoral thesis number 896, submitted May 24, 1948.

aeration and by inorganic nutrients, but no combination of factors was found to eliminate entirely the relative differences in decomposition rate between large and small quantities of plant residues added to soil. It is suggested that the activity of the microbial population which develops after the incorporation of crop residues in soil is limited not only by the chemical availability of the materials and by the physical factors mentioned, but also by the extent of space or surface available for development and proliferation of microbial cells. The important point is that small amounts of organic material in soil decompose more rapidly than larger quantities. These findings suggest that infrequent, large applications of organic residues to soil may do more toward building up or maintaining the organic matter level than frequent, small applications.

The effect of partial pressure of oxygen on nitrogen transformations and on organic matter decomposition in soil was investigated by means of a specially constructed apparatus. Various oxygen percentages were obtained by diluting air with nitrogen gas in various proportions. The relative proportions of nitrogen and air were regulated by passing each gas through calibrated capillary tubes of known flow rate and then into a mixing chamber. The resulting mixtures, varying from 0.2 per cent to 20 per cent oxygen, were then passed through samples of soil being incubated. The apparatus was arranged to permit frequent determination of carbon dioxide evolved in the decomposition processes.

The rate of decomposition of plant residues in soil was found to be a function of the partial pressure of oxygen. The higher the oxygen percentage in the gas mixture, the more extensive was decomposition of the added residues. Nitrogen release from these residues was greatest at the lowest oxygen percentage. However, the proportion of nitrate in the nitrogen released was greater at the higher oxygen percentages. In the decomposition of sucrose in soil, the evolution of carbon dioxide was not directly related to the oxygen percentage, being most extensive under partially anaerobic conditions in the case of a Webster clay. The immobilization of ammonium-nitrogen in the decomposition of sucrose was not affected by the oxygen tension. Where plant materials enriched with N^{15} were decomposed at various oxygen percentages, the proportion of total nitrogen released (derived from the soil organic matter) was not definitely related to the oxygen tension. However, under fully aerobic conditions, a greater proportion of the nitrogen released from both the soil and the added plant material was in the nitrate form. The nature of these findings indicates the need for further investigation of the effects of oxygen tension on microbial processes in soil.

SEPARATION OF CADMIUM FROM ZINC BY CONTROLLED CATHODE POTENTIAL ELECTRODEPOSITION¹

RICHARD J. BROUNS

From the Department of Chemistry, Iowa State College

In an effort to circumvent the tedious sulfide separation of cadmium from zinc, a thorough study of the electrodeposition of cadmium from cyanide solutions under controlled cathode potential conditions was made. Three primary standards were used: namely, hydrated cadmium sulfate crystals, $\text{CdSO}_4 \cdot 8/3\text{H}_2\text{O}$, anhydrous cadmium sulfate, and spectroscopically pure cadmium metal. The automatic electrodeposition apparatus of Diehl² was used in the experimental work. The deposits of cadmium were smooth and adherent, and the deposition was complete at a limiting cathode potential of -1.3 volt or more against a saturated calomel electrode. However, the weight of the deposits was usually high, even from samples of cadmium alone, using the official method, ASTM Method E-40-45. The results were not consistent enough to allow the use of an empirical correction factor. Quantities of cadmium up to 0.8 g. were deposited with an accuracy of about 1 per cent. The effects of varying the limiting cathode potential, initial current density, amount of alkali, amount of cadmium, and time of deposition were determined.

Analysis of the solutions with radioactive cadmium (the 43 day Cd^{115}) as a tracer showed that the deposition was complete under the conditions finally established. The amount of cadmium found undeposited was invariably less than 0.4 mg., and nearly all of this was lost from the electrodes in the wash water. Despite this loss, the weight of the deposit on the electrode was usually greater than the weight of cadmium taken. The cadmium deposits were analyzed for sulfide, sulfate, combined nitrogen, and cyanide; these elements were found to be absent in all cases. It is believed that the high results for cadmium were caused by the presence of cadmium oxide in the deposit.

The separation of cadmium from zinc was complete at a limiting cathode potential of -1.5 volt against a saturated calomel electrode from amounts of zinc as high as 0.5 g. per 200 ml. of solution. For amounts of zinc up to 1 g. a limiting cathode potential of -1.3 volt was found best. A number of deposits of cadmium obtained from cadmium-zinc mixtures were analyzed for zinc by using radioactive zinc (250-day Zn^{65}) as a tracer. Using 0.45 g. of zinc in 200 ml. of solution and a limiting cathode potential of -1.5 volt, the amount of zinc in the deposit of cadmium was less than 0.3 mg.

¹ Doctoral thesis number 914, submitted June 7, 1948.

² Harvey Diehl, *Electrochemical Analysis with Graded Cathode Potential Control* (The G. Frederick Smith Chemical Co., Columbus, Ohio, 1948), p. 8.

In order to obtain more accurate results for cadmium, the electrodeposits were dissolved and analyzed gravimetrically. The double ammonium phosphate method for cadmium was tested with samples of spectroscopically pure cadmium metal. The experimental directions of Miller and Page³ were followed, and the precipitate of cadmium ammonium phosphate was ignited to cadmium pyrophosphate. The results were good. It was found that the precipitate could also be dried to constant weight at 100°–103°C. but the composition of the compound was not constant enough for accurate work. A number of electrodeposits of cadmium obtained from alkaline cyanide baths were analyzed by the double ammonium phosphate method, and they were found to be impure, confirming the conclusions of the electrodeposition work. It was found that cadmium could be separated from as much as 1 g. of zinc by electrodeposition with controlled cathode potential, and the cadmium could then be determined quantitatively by conversion to the pyrophosphate with an average deviation of about 0.3 mg. on 0.3–0.5 g. of cadmium.

The solubility of cadmium ammonium phosphate was determined in a number of ammonium phosphate solutions covering a pH range of 6.6–8.75, in 60 per cent ethanol, and in water, by using radioactive cadmium as a tracer. The minimum solubility occurred at a pH of about 8.2 in aqueous phosphate solutions having a total ammonium ion concentration of 0.152 M. This minimum solubility was 2.4×10^{-6} M. The solubility in 60 per cent ethanol and in 1 per cent diammonium hydrogen phosphate was found to be 1.64×10^{-6} M and 3.16×10^{-6} M, respectively. These solutions are used to wash cadmium ammonium phosphate in the Miller and Page procedure. The solubility of cadmium ammonium phosphate in water was found to vary with the carbon dioxide content. Carbon dioxide-free water dissolved about 1×10^{-5} moles per liter of the compound, but ordinary distilled water dissolved about three times as much. A table of data and a graph of solubility versus pH are given in the full thesis.

³ E. H. Miller and R. W. Page, *Z. anorg. Chem.*, 28:233 (1901).

PRODUCTION AND SOME REACTIONS OF FURFURYL ALCOHOL¹

HORACE D. BROWN

From the Department of Chemistry, Iowa State College

A continuous process has been developed for the production of furfuryl alcohol in over-all yields of 95 per cent. The procedure involves passing the mixed vapors of hydrogen and furfural over a calcium stabilized copper chromite catalyst at atmospheric pressure. By keeping the reaction temperature below 140°C. other variables such as contact time, hydrogen to furfural ratio, and feed rate are rendered less critical. Under optimum conditions complete conversion of the furfural is obtained by one pass through a catalyst bed of ordinary length. For example, one pass through a 35 cm. bed with a contact time of about one second, a reaction temperature of $137 \pm 2^\circ\text{C}$., a feed rate of 23 g./hr., and a hydrogen to furfural ratio of 39/1 gave after distillation a 91 per cent yield of furfuryl alcohol, a 2 per cent yield of 2-methylfuran, and no measurable quantity of unreacted furfural. Increasing the reaction temperature, with the other variables unchanged, increased the yield of 2-methylfuran.

The preparation of the chromite catalyst is preferably carried out according to the procedure described by Holdren (3), with the decomposition temperature near 300°C. Glass beads are much more satisfactory as a catalyst carrier than activated charcoal. After 68 g. of furfural had been hydrogenated for each gram of catalyst used, complete conversion of the furfural was still obtained with a reaction temperature of 140°C.

Analysis of the reaction products was performed in the following manner. 2-Methylfuran was first separated by distillation of the wet product through a Claisen head. Furfuryl alcohol plus any unchanged furfural (if present) was then distilled through a Vigreux column in a nitrogen atmosphere at reduced pressure. The furfural in this fraction was determined from a refractive index measurement or a bisulfite-iodine titration.

β -Furfuryloxypropionitrile was hydrogenated at high pressure in the presence of Raney nickel and ammonia to give 80 per cent yields of γ -furfuryloxy-*n*-propylamine (b.p.₃ 83°–84°C., N^{20}_D 1.4845; the phenylthiourea derivative of the amine melted at 72.5°–73.5°C.). Similarly, β -tetrahydrofurfuryloxypropionitrile gave on reduction an 89 per cent yield of γ -tetrahydrofurfuryloxy-*n*-propylamine, b.p._{0.5} 71°–72°C., N^{20}_D 1.4609 (5). Reaction of the amines with various organic acids gave two series of salts which, like the amines, were very soluble in water and most polar solvents.

¹ Doctoral thesis number 867, submitted August 16, 1947.

Neither acidic nor basic hydrolysis of the β -furfuryloxypropionitrile gave the expected alkoxypropionic acid. Acid hydrolysis of β -tetrahydrofurfuryloxypropionitrile gave 42–53 per cent yields of an acidic material presumed to be β -tetrahydrofurfuryloxypropionic acid, b.p.₁ or less 135°–135.5°C., N^{20}_D 1.4614, d^{20}_4 1.154, N. E. 180. The crude *p*-bromophenacyl-ester, m. p. 36°–40°C., could not be readily purified by standard procedures.

Polymerization of γ -furfuryloxy-*n*-propylamine hydrochloride (formed in a cold dilute solution) in the presence of formaldehyde gave a gel. Subsequent treatment with excess alkali produced an oil or a spongy solid depending on the degree of polymerization. Hydrogenation of the oil in the presence of Raney nickel gave a clear viscous liquid which may have potential value as a plasticizer. The saturated polymer was soluble in water and reacted with concentrated hydrochloric acid without darkening.

Light amber colored polymers were prepared from 2-methylfuran by the addition of catalytic quantities of the following materials (at or below room temperature): SnCl_4 , AlCl_3 , FeCl_3 , BF_3 and ZnCl_2 . Chloral and iodine gave darker polymers. Condensation of the zinc chloride polymer with formaldehyde gave an insoluble infusible resin.

Attempted alkylation of 2-methylfuran by standard Friedel-Crafts procedures gave only resins. Acylation of 2-methylfuran was less successful than similar reactions with furan and 2,5-dimethylfuran. Whereas yields of 2-furyl methyl ketone in excess of 50 per cent were obtained by a previously described procedure (2), similar reactions with 2-methylfuran gave only about 10 per cent of the expected 5-methyl-2-furyl methyl ketone (semicarbazone, m.p. 185°–186°C.). 2,5-Dimethylfuran, acetyl chloride, and a stannic chloride catalyst gave a 61 per cent yield of 2,5-dimethyl-3-furyl methyl ketone (oxime, m.p. 76°–77°C.).

In the mercuration of 2-methylfuran, the substitution of mercuric acetate for the mercuric chloride previously used (1) gave a resin. Treatment of 5-methyl-2-chloromercurifuran with sodium thiosulfate gave a 68 per cent yield of 5,5'-dimethyl-2,2'-difuryl mercury, m. p. 101°–103°C. Reaction of 5-methyl-2-chloromercurifuran with acetyl chloride gave a 24 per cent yield of 5-methyl-2-furyl methyl ketone semicarbazone, m. p. 186°C.

Levulinic acid, purified by distillation at reduced pressure, was hydrogenated at 200°C. (500 p.s.i.) in the presence of 2 to 3 per cent by weight of Raney nickel to give a 97 per cent yield of 2-valerolactone.²

With an initial hydrogen pressure of 1590 p.s.i. and a maximum reaction temperature of 272°C., purified levulinic acid was hydrogenated in the presence of a Cu-Ca-Cr catalyst. A 62 per cent yield of 2-valerolactone and 21 per cent 1,4-pentanediol was obtained.

β -Angelicalactone was prepared in maximum yields of 50 per cent by the catalytic dehydration of levulinic acid. Reduction over a chromite catalyst gave 60 per cent 2-valerolactone and 11 per cent 1,4-pentanediol.

² During the course of regular patent proceedings it was learned that a prior application embodying essentially the same process had been filed. The patent referred to was granted early in 1945 (see reference 4).

LITERATURE CITED

1. GILMAN AND WRIGHT
1932. Jour. Amer. Chem. Soc., 55:3302.
2. HARTOUGH AND KOSAK
1946. Jour. Amer. Chem. Soc., 68:2639.
3. HOLDREN
1946. Iowa State College Jour. Sci., 21:33.
4. KYRIDES AND CRAVER
1945. U. S. Patent 2,368,366. Jan. 30.
5. UNTERMOHLEN
1945. Jour. Amer. Chem. Soc., 67:1505.

EFFECT OF FREEZING ON TENDERNESS AND ON ICE CRYSTAL FORMATION IN POULTRY AFTER VARIOUS PERIODS OF AGING¹

MARY AGNES FRANCES CARLIN

From the Department of Foods and Nutrition, Iowa State College

A study was made of the histological and palatability changes in roasters and fowl which occurred during freezing at 0°F. (−17.8°C.) and at −30°F. (−34.4°C.). The chickens were killed, eviscerated warm and aged thirty minutes, 1, 2, 6, or 24 hours prior to freezing or cooking. After aging, the birds were cut in half. In one part of the experiment both sides of the roaster were frozen, one at 0°F., the other at −30°F. Two replications were made at each aging period. In the other part of the experiment one half of the carcass was used as a fresh control and the other half was frozen. Four replications were made at 0°F. or −30°F. for each of the five aging periods.

The halves of chicken to be frozen were put into pliofilm bags and placed on a metal shelf in a 0°F. or a −30°F. room, where they were left for twenty-four hours. A constantan-copper thermocouple placed in the thigh of the bird was connected to a Leeds and Northrup Micromax which recorded the temperature every six minutes. Freezing curves were drawn from the data recorded by the Micromax. Samples of the raw fresh halves, cooked fresh halves, raw frozen and cooked frozen halves of birds were prepared for microscopic examination.

An average of approximately 3 hours, 24 minutes was required for all halves of chickens frozen at −30°F. to cool from 28°F. to 0°F., whereas halves frozen at 0°F. required 8 hours, 40 minutes. Thus the freezing rate at 0°F. was approximately one half that at −30°F. The fowl frozen at 0°F. and −30°F. usually took less time to freeze than the roasters. This might be explained partly by the fact that the fowl weighed less than the roasters. Length of aging the bird before freezing affected the freezing rate; those aged shorter periods of time required longer to freeze.

Total cooking losses at each aging period varied as much for frozen halves of birds as for fresh control halves. Losses in weight during cooking showed a linear relationship with total cooking time, except for the halves frozen at 0°F.

In general, the flavor and aroma scores showed little variation between treatments. The juiciness scores of fresh control halves aged twenty-four hours were two points lower than those for halves of birds aged thirty minutes; however, the decrease was not linear with aging. Halves of birds frozen at 0°F. showed a definite decrease in juiciness with aging, whereas freezing at −30°F. had little effect on the juiciness

¹ Doctoral thesis number 865, submitted August 5, 1947.

scores. Pectoralis secundus muscles were rated less juicy than the pectoralis major; however, the variation with aging was surprisingly similar.

In general, the tenderness of the fresh control halves of birds increased as aging progressed. An average tenderness score of 9.3 was reached for the pectoralis major muscle of fresh control halves of roasters and of 8.1 for fresh control halves of fowl in twenty-four hours of aging. The pectoralis secundus muscle of fresh control halves was rated more tender than the pectoralis major.

The tenderness curves for halves of birds frozen at 0°F. and -30°F. were quite different from those of the fresh controls. Freezing at the two temperatures, followed by thawing and cooking, definitely increased the tenderness of all frozen halves of birds except those aged 24 hours. Aging six hours or longer increases the tenderness to so great an extent that freezing after such aging periods can have little effect on tenderness. No differences in tenderness of poultry, owing to the freezing temperature, were noted.

Histological studies of the fresh control and frozen muscle fibers showed that the frozen muscle fibers were better differentiated and the cross striae more evident. The amount of disintegration varied greatly from bird to bird, but was obviously more extensive in fibers of birds frozen after short periods of aging than in fibers of the fresh control paired halves. In general, birds in which the muscle fibers have rather prominent cross striae, fewer waves and kinks, and considerable disintegration are rated higher in tenderness.

Vacuoles were the small cavities in fibers, assumed to be an indication of intra-fibrillar freezing, ice crystals having formerly occupied the spaces. They were found most frequently in cooked muscle fibers of birds aged thirty minutes, one or two hours before freezing. This evidence of intra-fibrillar freezing varied from bird to bird and was usually found in the straight part of the fiber. The length, width, and shape of the vacuoles varied. In cooked fibers the vacuoles were filled with a granular substance. Indentations, the small depressions in the sides of muscle fibers presumed to result from pressure of ice crystals between fibers, were found more frequently in fibers of birds frozen at 0°F.

From the evidence obtained in this study, it appears that freezing poultry muscle at -30°F. and 0°F. results in some intra-fibrillar freezing and some inter-fibrillar freezing. The size and location of ice crystals are determined by the rate of freezing, the extent of aging, and the histological structure of muscle tissues at the time of freezing.

DIHYDROXYPHENYLALANINE METABOLISM BY KIDNEY TISSUE¹

ROBERT EDWARD CLEGG

From the Department of Chemistry, Iowa State College

The metabolism of the amino acids, tyrosine and dihydroxyphenylalanine, by normal and scorbutic guinea pigs has attracted considerable attention during the past decade because of the observed dependence of the metabolism of these amino acids on the adequacy of vitamin C nutrition of the animal. This phenomenon has also been observed *in vitro*, for vitamin C is definitely related to the oxygen consumption of surviving liver and kidney slices of the guinea pig in the presence of tyrosine and dihydroxyphenylalanine, respectively. However, in order to successfully analyze a series of metabolic events, the systems responsible for the various steps must be separated one from the other. Since this cannot be accomplished by the use of the intact animal or tissue slices, tissue extracts have been employed to investigate the enzyme systems responsible for the metabolic series of events in the metabolism of dihydroxyphenylalanine by guinea-pig kidney tissue.

In spite of the previous observations that vitamin C was related to the metabolism of dihydroxyphenylalanine in the intact animal and in surviving kidney slices, the ability of kidney extracts, prepared from the kidney of scorbutic guinea pigs, to metabolize the amino acid was essentially the same as the activity of normal kidney extracts. The addition of crystalline ascorbic acid resulted in no additional activity.

The activity of the normal kidney extracts in the presence of dihydroxyphenylalanine and hydroxytyramine showed that the amino acid was decarboxylated by dihydroxyphenylalanine decarboxylase, and then amine oxidation of the hydroxytyramine by the enzyme, amine oxidase, occurred. Furthermore, the catechol nucleus of the amino acid disappeared during the incubation. The balanced experiments, in which the oxygen consumption, carbon dioxide evolution, and ammonia formation were correlated, demonstrated the failure of the oxygen consumed to account for the disappearance of the catechol nucleus of the amino acid during the incubation period. The hydrogen peroxide, formed as the result of amine oxidation, failed to account for the disappearance of the catechol portion of the amino acid. In addition, the stability of the dihydroxyphenyl group of the amino acid was observed in the presence of the hydrogen peroxide formed by the action of a *D*-amino acid oxidase preparation on *D*-methionine.

However, inhibition studies, with dihydroxyphenylalanine and hydroxytyramine as substrates, demonstrated the ability of cyanide and

¹ Doctoral thesis number 898, submitted June 4, 1948.

semicarbazide to inhibit the disappearance of the catechol nucleus even when the amine oxidation was proceeding at a nearly normal rate. Although cyanide inhibition of the dihydroxyphenylalanine decarboxylase was shown to be reversible, reversible cyanide inhibition of the diphenolic disappearance was not observed. Information obtained by the use of other known enzyme inhibitors was not as informative.

In addition to the disappearance of the catechol group of the amino acid, as evidenced by the reduction of the diphenolic value during the incubation period, the destruction or modification of the 3,4-dihydroxyphenyl group of the amino acid was manifested by the change in the character of the ultraviolet absorption spectrum of the deproteinized extracts. The maximum of approximately 280 millimicrons, characteristic of the catechol nucleus, was eliminated, and a new maximum at approximately 255–260 millimicrons was observed. The substance exhibiting the maximum at 255–260 millimicrons was soluble in butyl alcohol. The absorption maximum in the butyl alcohol and in a water solution after removal of the butyl alcohol was essentially the same as that observed in the deproteinized extracts.

An examination of the ability of other tissues to metabolize the amino acid demonstrated that the activity of dihydroxyphenylalanine in guinea-pig liver extracts was much lower than in kidney extracts. However, by employing hydroxytyramine as the substrate, the activity of the amine oxidase in the liver extracts was shown to be comparable to that of the kidney extracts. On the other hand, rat kidney extracts, although exhibiting the ability to consume oxygen in the presence of the amino acid and the ability to cause the disappearance of the dihydroxyphenyl groups, gave neither the same oxygen-to-substrate ratio nor the same pH-activity relationship observed in the case of the guinea-pig kidney extracts.

Dialysis did not reduce the activity of the guinea-pig kidney extracts and ammonium sulfate fractionation, followed by isoelectric separation, did not result in a stable and active enzyme preparation. In fact, a considerable loss of activity was experienced when the above mentioned fractionation methods were employed.

Inasmuch as conjugation of phenol and catechol type compounds is a well-known detoxification mechanism, the possibility of a conjugation reaction being responsible for the diphenolic disappearance was investigated. The method usually used to demonstrate catechol conjugates—acid hydrolysis—failed to reveal the presence of such a compound.

However, the observation of the disappearance of the catechol nucleus of the amino acid in a manner other than oxidation and the evidence of a substance in the deproteinized filtrates with a spectrum decidedly different from that exhibited by catechol and dihydroxyphenylalanine strongly suggest the existence of another enzyme system which operates in the metabolism of dihydroxyphenylalanine by guinea-pig kidney extracts.

RADIO-FREQUENCY RADIATION FROM ELECTRIC DISCHARGES IN GASES¹

WILLIS LAURENS EMERY

From the Department of Electrical Engineering, Iowa State College

Considerable work has been done in recent years on the radio-frequency oscillations arising from electric discharges in gases. Analyses of oscillations in mercury vapor, inert gases, and air have been reported. For the most part, these investigations have been concerned with gases at relatively low pressures. However, the work on air is an exception which is closely allied to the practical interference problem involving corona discharges from pointed conductors. The present work was undertaken to study the effect of some of the individual constituents of air on the radiation produced by such discharges. Radio-frequency spectrograms were made for negative point-to-plane corona discharges in pure hydrogen and pure oxygen. Both the hydrogen and oxygen were prepared by electrolysis and then purified by exposing them to a red-hot platinum filament.

Radiation measurements were made inside a round wave guide of smaller than critical diameter. The discharge tube was mounted at one end of the wave guide and a pick-up probe was mounted at the other end. The probe was made of a 0.1 megohm resistor in parallel with a condenser consisting of a pair of square plates three centimeters on edge and spaced one centimeter apart. The combination was connected across the input of an impedance-matching stage which transferred the energy to the antenna terminals of a communication receiver. A signal derived from the automatic-volume-control voltage of the receiver was used to drive a recording element.

In general, no radiation was obtained from the corona discharge in hydrogen at pressures ranging from 155 to 745 mm. of mercury. There was just one exception. Some pick-up was obtained on the two lowest frequency bands when the pressure was 155 mm. of mercury. A spectrogram made of the radiation in the 0.55 to 1.5 megacycle band showed a continuous output of uniform intensity throughout the range. Before a recording could be made of the 1.4 to 3.0 megacycle band, however, the radiation had completely disappeared. Evidently the element responsible for the output had been removed in some manner by continued exposure to the discharge.

Just prior to the above observation, a run had been made at a pressure of 145 mm. of mercury. At this pressure a moderately slow relaxation oscillation was set up. The condenser of the power supply periodically discharged through the tube with a high current. During

¹ Doctoral thesis number 871, submitted August 25, 1947.

the discharge period, the tip of the cathode was covered with an extensive glow. Apparently this operation temporarily modified the cathode in such a way as to make generation of radio frequencies possible when the pressure was raised for the next observation.

Since corona discharge in hydrogen converts it to a very active form which readily reduces oxides, there can be little doubt that the tungsten cathode had a clean metallic surface in the vicinity where the corona was formed. Temporary exposure to the extensive glow discharge may have started reduction of the oxide further down on the shank of the electrode through fissures near the end. Increasing the pressure slightly would narrow the area over which the discharge originated but still keep it large enough to include some of the newly opened fissures. As the discharge progressed, more and more of the oxide surrounding the fissure would be reduced until a relatively large bare metallic surface was produced. The transitory presence of such fissures could have been responsible for the oscillations which were observed.

In contrast with hydrogen, radio-frequency output was observed on all runs with oxygen except those at very low pressures (8 mm. of mercury). A continuous spectrum was produced for pressures near atmospheric. The intensity of the oscillations was a direct function of the applied voltage. Some observations were made at frequencies as high as 30 megacycles, but the intensity at the higher frequencies was so greatly reduced that most of the subsequent observations were limited to the range 0.55 to 3.0 megacycles. In this range, it was found that the continuous band of frequencies which was characteristic of atmospheric pressure broke up into narrow bands and finally into single frequency signals as the pressure was reduced. Successive spectrograms taken under identical conditions indicated that some of these signals gradually increased in frequency, while others decreased in frequency, and still others oscillated about a fixed region. The frequency shift was in a purely random manner. All types occurred in a single set of recordings. Of course, there was no positive assurance that each apparent trend actually was a gradual transition of the same signal because there was an appreciable time lag between successive recordings. It is entirely possible that separate disturbances arose and then disappeared, but probably both effects were contributing factors.

With oxygen in the tube, it is practically certain that there was never very much surface on the cathode which was not covered with oxide. The oxide coating had to be continually broken down to allow passage of the arc current. In a short time, the fissures developed would tend to be sealed by the oxidation process.

A tentative explanation of the oscillation process can be made on the basis that such fissures are primarily responsible. An oscillating gas tube has been described by Kleinwächter² in which the oscillations are produced by strongly constricting the arc through a small orifice. A high voltage gradient exists through the area of arc constriction, and it

² Archiv für Elektrotechnik 34:523-30 (1940).

together with the high current density leads to intense ionization. Since the positive ions which are formed there are swept out of the area with a greater velocity than the average thermal velocity of the gas molecules, an evacuated region soon develops. Consequently, the arc is extinguished. As the gas pressure again rises in the constricted area due to diffusion of neutral molecules from the outside, conditions become favorable for the initiation of a new arc and the process is repeated. A similar interruption of the portion of current flowing through a particular fissure could occur due to an evacuation at the mouth. The accumulation of positive ions at the base of the fissure would also assist in choking off the current and preparing for the next ignition of the arc through that area.

The tendency for the frequency of a particular signal to either increase or decrease with time could be explained on the basis that the fissure involved is either being closed by further oxidation or being opened by breakdown of the oxide. Other theories do not allow erratic performance of this sort. The fact that very few of the oscillations occurring at a given time bear harmonic relationships indicates that they have separate origins. The more erratic character of the oscillations at the higher pressures could be due to the fact that more gas molecules are present; hence, the building up and tearing down processes would take place at a more rapid rate. The continuous band observed at atmospheric pressure could easily arise from rapid shifts of the generated frequencies.

The proposed theory is substantiated by the observation that the cathode was always cleaned of oxide near the tip after a series of discharges in hydrogen and was always covered with oxide after a series of discharges in oxygen. Nevertheless, the theory must be regarded as tentative because some important points could not be checked with the present apparatus. Foremost among these points is the question of just how the frequency shift takes place from one moment to the next. A broad-band panoramic receiver would be required for such an observation. A receiver of this sort would also assist in checking another important point. The pressure could be shifted slightly while under observation to see if an instantaneous frequency shift were made in the proper direction. Finally, inert gases should be studied with both clean and oxide-covered electrodes to see if there is a difference in the radiation produced.

LIFE HISTORY AND ECOLOGY OF THE CANVAS-BACK,
NYROCA VALISINERIA (WILSON), IN SOUTH-
EASTERN OREGON¹

RAY CHARLES ERICKSON

From the Department of Zoology and Entomology, Iowa State College

The recent trend of wildlife studies has been away from field research on broad groups or ecological communities of plants and animals toward intensive investigations of single species and the coactions of these species with their environments. This research into the life history and ecology of the canvas-back, *Nyroca valisineria* (Wilson), in southeastern Oregon (mainly on the Malheur National Wildlife Refuge in Harney County) during 1942, 1946, and 1947 has followed the latter trend. Information obtained in this manner may form the basis for management practices to be employed in maintaining or increasing the numbers of desirable species.

Canvas-backs usually appeared on the research area early in March and were most abundant between March 15 and April 20. The last spring migrants passed through by May 10. Approximately 18,000, 16,000, and 15,500 canvas-backs passed through the refuge during 1942, 1946, and 1947, respectively. Most of the earliest migrants were single males. About 68 per cent of the canvas-backs were paired during the height of migration. Average male/female ratios for the three years were 1.47/1, 1.52/1, and 1.63/1, based on counts of 7,162 migrants. Of the canvas-backs migrating into and through the area in spring 564 or 3.1 per cent in 1942, 308 or 1.9 per cent in 1946, and 236 or 1.5 per cent in 1947 remained during the breeding season.

The average flight speed of canvas-backs was about 46 miles per hour. Distribution of migrant canvas-backs on the larger lakes appeared governed chiefly by water depths, cover-water interspersions, and species and availability of submerged plants. Warm weather in the spring was correlated with an accelerated migration from the refuge. Departures were delayed during cold weather. Courtship and mating of the canvas-back were discussed.

Nesting seasons for each year, based on field observations, were from April 10 to August 5, 1942, or 118 days; March 22 to July 31, 1946, or 132 days; and April 20 to July 14, 1947, or 86 days. The drake took no part in selection of the nest site, nest construction, incubation, or brood-rearing. The drake defended the mate, not a "territory," against intraspecific intrusion on the waiting site or "loafing" area.

The most important condition determining the use of habitat in nesting was cover-water interspersions. In contrast with the migration

¹ Doctoral thesis number 892, submitted March 16, 1948.

habitat the nesting areas contained a larger proportion of emergent vegetation to open water. Most canvas-back nests (83.8 per cent) were found in vegetation containing hardstem bulrush. Utilization of vegetation in nest construction was determined largely by the pliability of the plant materials. The distance from nests to flushing areas varied from 0 to 75 feet and averaged 11.7 feet. Details of nest construction and descriptions of the plant cover were discussed.

The average number of eggs laid by canvas-back females in interpreted initial nesting attempts was 9.9 for the three years. In 74 observed canvas-back nests 482 canvas-back eggs, 497 redhead (*Nyroca americana*) eggs, nine ruddy duck (*Erismatura jamaicensis rubida*) eggs, one American pintail (*Dafila acuta tzitzihua*) egg, and one American coot (*Fulica a. americana*) egg were deposited. This gave an average of 18.2 eggs for each nest in 1942, 9.9 in 1946, and 10.0 in 1947. Fifty-nine (80 per cent) of the observed canvas-back nests contained foreign eggs. Female canvas-backs rarely parasitized other nests on the research area.

The percentage of nest success was inversely proportional to the percentage of females renesting and the promiscuous egg-laying of other species of waterfowl in canvas-back nests. The percentage of canvas-back females successful in nesting, taking renesting into consideration, was estimated to have been 27.6 in 1942, 76.5 in 1946, and 70.0 in 1947. About 57 per cent of the observed canvas-back nests were unsuccessful. About four-fifths of the unsuccessful nests were abandoned and one-fifth was destroyed. Four-fifths of the abandoned nests were believed deserted because of nest parasitism. American ravens (*Corvus corax sinuatus*) accounted for all but one of the destroyed nests.

Of all eggs deposited in observed canvas-back nests the percentage hatching was 6.7 in 1942, 59.8 in 1946, and 42.2 in 1947. Eggs lost over the side of the nest was the most important factor reducing the number of canvas-back eggs remaining to hatch in parasitized nests. Of an average of 7.3 canvas-back ducklings hatched in parasitized nests, six were canvas-backs and two were of the intruding species. The ratio of canvas-back/redhead ducklings hatched in canvas-back nests was 1.44/1 in 1942, 4.35/1 in 1946, and 6.46/1 in 1947.

Various hypotheses on conditions which stimulated the parasitic habit among birds, and with ducks particularly, were discussed. Discordance in successive events of the breeding cycle of the intruding species, apparently as a reaction to external stimuli of weather and habitat conditions, seemed mainly responsible for the incidence of sustained nest parasitism in 1942. Promiscuous egg-laying was most closely correlated with fluctuating water levels. Variations in breeding densities of host and intruding species, advancement of the nesting season, species of plant nesting cover, and period in the nest history did not seem to be factors which governed the incidence or extent of parasitic ovipositing. Canvas-back nests were more heavily parasitized than redhead nests in 1942. The fertility of both host and intruder eggs was similar. The intruding female did not (1) assist in the construction or maintenance of the host's nest, (2) remove down feathers from its body

for lining the nest bowl, (3) turn the eggs, (4) form the clutch into a concave, body-fitting layer, (5) cover the eggs prior to leaving the nest, nor (6) incubate. Nest parasitism was detrimental to the intruding species through the low success of intruded eggs even during high nesting success of the host nests.

Canvas-back juveniles began to fly shortly after the tenth week. Observed duckling mortality was negligible. The annual reproductive increment of canvas-backs on the refuge was 196 in 1942, 494 in 1946, and 347 in 1947. The adult/surviving juvenile ratio for canvas-backs on the Malheur Refuge was 1/0.56 in 1942, 1/1.97 in 1946, and 1/1.70 in 1947.

Diseases and parasites, postbreeding habits of juveniles and adults, food habits, and fall migration of the canvas-back were discussed.

Management of the canvas-back was consistent with over-all wildlife management on the refuge. Cropping, haying, grazing, water level manipulation, and muskrat management were useful tools in improving habitat for waterfowl utilization. Stabilized water levels during the nesting season were vital to suitable nesting habitat and increased nesting success of the canvas-back and certain other waterfowl. Predator control on the refuge should continue to be primarily concerned with suppression of the numbers of ravens and coyotes (*Canis latrans lestes*).

INHERITANCE OF PROTEIN, ZEIN, TRYPTOPHAN, VALINE, LEUCINE, AND ISOLEUCINE IN TWO MAIZE HYBRIDS¹

KENNETH JOHN FREY

From the Department of Agronomy, Iowa State College

INTERRELATIONSHIPS OF PROTEIN, ZEIN, TRYPTOPHAN, VALINE, LEUCINE, AND ISOLEUCINE

A review of the literature indicates that corn protein is nutritionally inadequate. This inadequacy results from zein, the alcohol soluble endosperm protein, being devoid of lysine and tryptophan, two of the indispensable amino acids. Zein comprises about 50 per cent of the endosperm protein and is linearly related to total protein. Since about 85 per cent of the annual corn crop is fed to livestock on the farm where it is grown, there is considerable interest in any attempt to improve the protein quality of corn. One approach to improvement is controlled selection and breeding of corn for increased lysine and tryptophan content. This requires the assaying of a great number of samples, and therefore has not been feasible until the advent of rapid assay procedures in the past decade.

In anticipation of a large scale program to improve corn protein quality, two maize crosses were studied to obtain information about the interrelationships of certain amino acids and protein, and the inheritance of protein and some of its components. Individual ear samples of Illinois high and Illinois low protein corns and of the F_1 , F_2 , and backcross generations of a cross between the two were analyzed for protein, zein, tryptophan, valine, leucine, and isoleucine. Also, protein, zein, and tryptophan analyses were made on similar material for the cross Hy x I198. The parents and F_1 's contained about 15 to 20 samples, and the F_2 's and backcrosses about 80 to 100.

The correlation coefficients among protein, zein, valine, leucine, and isoleucine ranged from +0.56 to +0.97, with the modal class from +0.80 to +0.90. After correction for common elements all of these correlations were highly significant. This indicates close relationships among these variables. Correlations of tryptophan with any of the other variables ranged from +0.14 to +0.57, which indicates only a slight relationship. However, all of the correlations were positive, which means that all of the components studied increased simultaneously.

Exponential regressions were calculated for the equation $Y = aX^b$, where Y is the expected value of the dependent variable, a is a constant, X is the independent variable, and b is the exponential regression of Y on X . When b is unity, the dependent and independent variables increase

¹ Doctoral thesis number 887, submitted March 11, 1948.

at the same relative rates, and when b is greater or less than unity, the dependent variable increases at a greater or lesser relative rate, respectively, than the independent variable. The exponential regressions of zein on protein were all significantly greater than unity. This means that zein becomes a greater proportion of the corn protein as protein percentage increases. Thus, selection for high protein corn will be accompanied by a decrease in the quality of the protein. Further evidence of this relationship is the fact that tryptophan increases at a much slower rate than protein. The exponential regressions of tryptophan on protein were all significantly less than unity. Valine, leucine, and isoleucine increased at approximately the same rates as protein percentage.

Total protein and non-zein protein were contrasted as criteria of tryptophan content by the use of exponential regressions. It seems logical that the variable which has a rate of increase most like that of tryptophan will be the better criterion of tryptophan content. In each of the six cases studied the exponential regression of tryptophan on non-zein protein was larger than that of tryptophan on total protein, indicating that non-zein protein was the better criterion of the two.

Correlations between protein percentage and weight of grain per plant ranged from -0.03 to -0.48 . This corroborates previous evidence that an inverse relationship exists between protein percentage and yield in corn. This imposes a limit on the improvement which can be made when selections are based on total protein. High protein strains will tend to be lower in yield, and the production of protein and tryptophan per acre may not be increased materially.

In summarization, it appears that a program to improve the feeding quality of corn should emphasize selection for high-yielding medium protein corn in which there is a favorable zein-protein balance. This should increase the lysine and tryptophan produced per acre.

INHERITANCE OF PROTEIN AND CERTAIN OF ITS COMPONENTS

For protein, tryptophan, valine, and isoleucine percentages in the high \times low protein cross, the F_1 means were equal to, or slightly below, the low parent means. The Bc_2 means of these variables were not significantly different from the F_1 or low parent means. The F_1 and Bc_2 mean leucine percentages were higher than the low parent mean. In the Hy \times I198 cross, the F_1 and Bc_2 means of protein and zein percentages were very close to the low protein parent means, while the F_1 mean tryptophan percentage was midway between the two parents. From these data it seems safe to conclude that there is complete dominance of low protein, zein, valine, and isoleucine percentages. Low leucine percentage is partially dominant. Low tryptophan percentage is completely dominant in the high by low protein cross, but not in the Hy \times I198 cross. Dominance of low protein percentage may be a serious handicap in the production of high protein double crosses. The production of a high protein double cross would require four high protein inbreds which would eliminate most of the existing lines. The same holds for protein components.

Smith and Charles have given formulae for the calculation of

expected F_2 and backcross means upon the assumptions of arithmetic and geometric gene interaction. The data in the Illinois high x Illinois low protein cross conformed very well to the means calculated upon the assumption of arithmetic gene interaction. The exceptions were tryptophan and isoleucine in the Bc_2 and leucine in the Bc_1 .

The Castle-Wright formula for calculating minimum gene number was used on the data of the Illinois high-low protein cross, and the estimated gene numbers were as follows:

•

CHARACTER	MINIMUM GENE NUMBER
Protein percentage	22
Zein percentage	6
Tryptophan percentage	15
Valine percentage	8
Leucine percentage	8
Isoleucine percentage	6

These numbers are rather small compared to previous estimates of gene numbers determining quantitative characters. Another indication that a small number of genes may be involved in each case is the fact that the parental means are recovered, or almost recovered, in an F_2 of 102 individuals.

HISTOLOGICAL, PHYSICAL, AND ORGANOLEPTIC CHANGES IN THREE GRADES OF BEEF DURING AGING¹

DOROTHY LUCILE HARRISON

From the Department of Foods and Nutrition, Iowa State College

The histological, physical, and organoleptic changes during varying storage periods at 34°–36° F. of four beef muscles from the carcasses of four animals were studied. In addition, the effect of moist heat on collagenous and elastic connective tissues was observed. Animals 1 and 2 were yearling steers, carcass grades, good; animal 3 was a steer, carcass grade, commercial; and animal 4 was an eight-year old dairy cow, carcass grade, cutter. The paired psoas major, longissimus dorsi, semitendinosus, and biceps femoris muscles were utilized. Twenty-four hours after slaughtering each animal, the muscles were dissected from the carcass, most of the visible fat removed, and divided into roasts. Each longissimus dorsi was divided between the twelfth and thirteenth rib into the rib portion and the loin portion, and each portion was cut into three roasts. All other muscles were cut into three roasts each. The roasts were placed unwrapped on enamel trays and stored in the meat cooler. The aging periods (1, 2, 5, 10, 20, and 30 days) of the roasts were assigned at random. To study the effect of moist heat on the connective tissues, strips of tendons and ligaments were heated in distilled water.

For cooking, the roasts were placed on a rack in a kettle deep enough to cover them with bland lard which was held at a temperature of 96°–98°C. They were cooked to an internal temperature of 70°C. Data were recorded before and after cooking the roasts to determine: (1) the percentage loss in weight during aging and cooking, (2) the percentage decrease in length and width and the percentage increase in thickness of the roasts during cooking, (3) shear force of the cooked roasts, (4) percentage of press fluid of the cooked roasts, (5) pH measurements of the cooked and uncooked roasts, and (6) palatability scores for aroma, flavor, tenderness, and juiciness of the cooked roasts.

Histological sections were made from samples of the uncooked and cooked roasts to determine the microscopic changes during the storage of beef and the proportion of connective tissue in the muscles studied. Arbitrary numerical evaluations were used to compare the relative proportion of collagenous and elastic connective tissues in the muscles.

In addition to the pH determinations made on the roasts, the pH of a sample of muscle from the fore-part of the chuck was determined soon after the slaughter of each animal and at various intervals thereafter.

The roasts from each muscle gradually decreased in weight as

¹ Doctoral thesis number 862, submitted July 18, 1947.

storage time increased. Gradually the exposed surfaces of the roasts became dark and dry. After thirty days of storage these surfaces were covered with a crust about $\frac{1}{4}$ inch thick, and occasionally had small areas of mold on them. The surfaces of the meat next to the trays were moist and sticky from the fifth day through the thirtieth day of storage.

In general, the weight lost during cooking decreased slightly as the aging period increased. The decrease in length of the roasts during cooking was not always linearly related to the time of aging the roasts before cooking. All but one of the 120 roasts decreased in width during cooking, and all but one roast increased in thickness during cooking. These data varied greatly within the roasts from a given muscle.

Judges' scores for aroma and flavor of the roasts varied only slightly among the muscles but varied considerably among the animals. Aroma and flavor scores for a given animal varied little during the first to twentieth days of aging, but dropped slightly after thirty days of aging. The less desirable aroma and flavor in the roasts stored thirty days were attributed to a musty odor and an acid or "high" flavor. The juiciness of the cooked roasts remained about the same for the first twenty days of aging, then dropped slightly after thirty days of aging. The average press fluid values followed the same pattern as the juiciness scores. Tenderness scores and shear force of the roasts indicated a gradual increase in tenderness with aging, but such increase in tenderness was not always linear. Analysis of variance of scores showed that the change in tenderness with aging, the variation among muscles, and the variation among animals were highly significant.

Acidification of muscle occurred post mortem. The rate of this acidification varied among the animals, but was rapid during the first one to two hours. During storage the pH of uncooked muscle dropped slightly, then rose slowly. The cooked roasts were slightly more alkaline than the uncooked roasts.

Strips of tendons heated in distilled water progressively decreased in length and softened as the temperature of heating increased and as the time of heating increased up to certain periods. Tendons from animal 4 did not soften as readily as those from the other animals. There was also variation in the softening of identically treated samples from the same animal. The increase in width and thickness of the tendons varied tremendously and followed no regular pattern except that the higher the temperature of heating, the greater the number of samples which increased in width.

Strips of elastic tissue decreased in length when heated but the decrease was small compared to that which occurred in the collagenous tissues. Shear force of these tissues showed that under the conditions of this study, samples heated for one to two hours were from two to four times more tender than they were before heating.

Histological characteristics of the muscles followed a general pattern during the first five days of storage. The most tender muscle, the psoas major, differed from the other muscles in that, in general, it did not

exhibit longitudinal striae and it contained small amounts of connective tissue. The fibers of this muscle were slender and the cross striae widely spaced and distinct. The fibers of the other muscles varied from straight fibers with nodes to fibers containing z-z contractions, kinks, twists, and waves. Moderate to large amounts of collagenous connective tissue were present and the semitendinosus muscle contained dense strips of elastic connective tissue.

The muscle fibers of animal 4 appeared more gnarled and worn with age than the fibers from the muscles of the other animals. Sections made from the muscles of animals 3 and 4 contained large proportions of collagenous tissue, and in addition, those from animal 4 contained large amounts of fat between the muscle fibers.

Disintegration of the muscle fibers started at about ten days of storage and became more evident as time of storage progressed. The disintegration consisted of a destruction of the striae in strips of the muscle fibers resulting in fragility of the fibers.

THE INHERITANCE OF AGRONOMIC CHARACTERS IN BARLEY¹

ERHARDT R. HEHN

From the Department of Agronomy, Iowa State College

Two factor pairs differentiated the growth habit of winter Khayyam and the spring varieties, Manchuria 4396 and Selection 54. Khayyam and spring Manchuria 4471 differed by three factor pairs in respect to growth habit. Winter growth was manifested by interaction of the recessive alleles of three factor pairs designated as Sh_1sh_1 , Sh_2sh_2 , and Sh_3sh_3 . Spring habit was completely dominant in factor pairs, Sh_1sh_1 and Sh_3sh_3 , and incompletely dominant in Sh_2sh_2 . Any one of the three factor pairs in the homozygous dominant condition resulted in true breeding spring growth habit. Winter segregates were obtained from a cross of the spring varieties Coast x Manchuria 4396.

Earliness appeared to be conditioned by the interaction of several factors. One or more factors differentiated the varieties studied in respect to this character. The data indicated that the dominant allele of the growth habit factor, Sh_2sh_2 , imparted earliness to spring type segregates.

Two factor pairs for barbing of the awns were segregating in the F_2 and F_3 generations of rough awned Cape x smooth awned Wisconsin 38. Rough awnedness was dominant. Rough awned Khayyam and Selection 54, which possessed rough-tipped awns, differed by a single factor pair in respect to this character.

Evidence was obtained that degree of lateral floret development in the heterozygotes of two-rowed x six-rowed crosses was influenced by earliness.

Cape and Wisconsin 38 differed by three factor pairs for rachis internode number.

In the cross of Cape with Wisconsin 38 the long basal rachis internode of Wisconsin 38, designated *Bibi*, was recessive and governed by a single factor pair. This factor pair was linked with characters, Rr , Ss , and L_2l_2 , located in chromosome V. The order and recombination percentages of the four genes in this linkage group were: $bi-16.1-r-34.7-l_2-29.3-s$.

Severity of bacterial blight, *Xanthomonas translucens* (J.J. and R.) Dowson, in the F_2 population of seven crosses, was associated with earliness.

A single factor pair governed reaction under field conditions to stem rust, *Puccinia graminis tritici* Erikss and Henn., in the cross of susceptible Khayyam with resistant Selection 54.

Reaction to mildew, *Erysiphe graminis hordei* Marchal, was con-

¹ Doctoral thesis number 901, submitted June 4, 1948.

trolled by two independent factor pairs in the cross of susceptible Manchuria 4471 with resistant Chevron. Complete field resistance to what appeared to be Race 6 was manifested only by plants homozygous dominant for both factor pairs.

COMMERCIAL EXTRACTION OF SOYBEAN OIL USING NON-INFLAMMABLE SOLVENTS¹

EUGENE GRAHAM HOLLOWELL

From the Department of Chemical Engineering, Iowa State College

The most efficient method of removing oil from soybeans is to extract it with solvents. Hexane, the most widely used solvent, is highly inflammable; consequently, it has been used only in large plants where elaborate safety precautions can be enforced. Trichloroethylene is the most promising of the non-inflammable solvents, but because of its high cost can be used only in systems having low solvent losses.

Research at Iowa State College previous to this work resulted in the development of an extraction system using a screw conveyor to carry the soybean flakes through trichloroethylene (1) (2). In this work the Redler conveyor was adapted for use in small scale extraction plants using trichloroethylene. Following several years of operation of a pilot plant, a commercial plant capable of processing fifteen tons of soybeans a day was constructed and operated successfully at Plainfield, Iowa.

The use of continuous conveyors of the Redler type greatly reduces the amount of fine meal produced because the flakes are not agitated as they are carried through the solvent. Such a conveyor also enables one to obtain excellent countercurrent extraction.

Simple analytical tests for the detection of trichloroethylene in soybean oil, soybean meal, and water are based upon the Fujiwara pyridine test for chloroform. Most other tests necessary for plant control can be run according to standard methods approved by the National Soybean Processors Association.

Soybeans containing as high as 14 per cent moisture were successfully extracted in the commercial plant. The beans were cracked, heated to 140°-150°F., and rolled into flakes with 24-inch diameter rolls. With an extraction time of twenty minutes, meal containing 0.8 per cent oil was obtained from flakes 0.010 inches in thickness. The oil obtained was considerably better in quality than required by commercial standards.

The solvent-oil solution, or miscella, was given a preliminary filtering as it left the extraction chamber by being passed through forty mesh screens, which were continually being cleaned by fresh flakes. The fine meal remaining in the miscella passed through the evaporator and was filtered by gravity in home-made Kelly-type filters. About 0.05 per cent of the beans was obtained as fines.

A long vertical tube natural circulation evaporator was used for evaporating most of the trichloroethylene from the oil. The tubes were

¹ Doctoral thesis number 868, submitted August 23, 1947.

1 inch in diameter and jacketed with steam for a length of 17 feet. In the evaporator the miscella was concentrated from 20 to 80 per cent oil. An overall heat transfer coefficient of 65 B.t.u./hr./sq. ft./°F. based on the inside area was obtained in the evaporator. Because of the high velocity of the vapor and liquid passing through the rising film evaporator, it was not necessary to filter fine meal from the solution being concentrated.

Solvent was removed from the concentrated filtered solution containing 80 per cent oil by allowing the trichloroethylene to diffuse into a current of steam. A number of different types of stripping devices were tried. The most satisfactory were columns packed with Berl saddles operated above 100°C. at atmospheric pressure. A 14-inch diameter column 14 feet long packed with 1-inch Berl saddles was used in the commercial plant. The most efficient packing material tried was a type of re-enforced spiral weave wire.

At times during the operation of the Plainfield Plant a small amount of oil would be entrained by the steam passing through the stripping column. This oil produced heavy emulsions containing solvent in the condenser and in the solvent-water separator. The heavy emulsions were eliminated and the solvent recovered by a special type of emulsion-breaking apparatus.

After leaving the Redler extraction section, the soybean flakes passed through a drainage section, and then through a steam jacketed section of the Redler conveyor in which part of the trichloroethylene was evaporated. The partially dried meal leaving the Redler drier passed into a long tubular drier 1 foot in diameter containing a ribbon conveyor 2 inches in width with a pitch of 1 foot. From the tubular drier the meal fell into a toaster identical in construction with the drier. The ribbon conveyors in both the drier and toaster were fitted with devices for stirring the meal. Meal left the toaster through a barrel valve and was then moistened, cooled, and ground.

Vapor was removed from one end of the Redler drier and from a point between the tubular drier and toaster. The vapor leaving at the latter point contained fine meal dust, which was removed by spraying the vapor with hot water before it entered the condenser.

Tubular heat exchangers with the vapor condensing inside the tubes were used throughout the system. Noncondensable gases were vented through the flakes entering the extractor. A small blower was used to aid in venting the condensers. Some corrosion of the iron occurred in the condenser and in other parts of the system where water and trichloroethylene could condense. The corrosion problem was not serious. Solvent and water leaving the condensers passed into a solvent-water separator from which the water overflowed to the drain. Solvent loss was 8 to 10 pounds per ton of beans processed and will undoubtedly be reduced in the future.

Milkweed seeds containing 23 per cent oil were extracted to 4 or 5 per cent oil in the pilot plant apparatus using trichloroethylene and an extraction time of 15 minutes. A good quality of oil was obtained.

Cottonseed meats containing 35 per cent oil were extracted to give a meal containing 2 per cent oil in the pilot plant with an extraction time of thirty minutes. A good quality meal but a poor quality oil was obtained.

The oil content of oatmeal was reduced from 6.5 per cent to less than 1 per cent in the pilot plant apparatus. Filtering the fine meal from the solvent-oil solution was found to be exceedingly difficult.

Using an extraction time of thirty minutes in the pilot plant the oil content of corn germs was reduced from 50 to less than 3 per cent. The oil and meal appeared to be of a satisfactory quality.

Continuous operation of the commercial plant has proven conclusively that soybeans can be profitably extracted in a small-scale plant using non-inflammable trichloroethylene. Behavior of the pilot plant has indicated that the process can be applied to the extraction of oil from many materials other than soybeans using trichloroethylene or similar non-inflammable solvents.

LITERATURE CITED

1. KIRCHER, C. E.

1940. Development of a plant for continuous counter-current extraction of soybeans with trichloroethylene. Unpublished Ph. D. thesis. Iowa State College Library, Ames, Iowa.

2. McCracken, W. L.

1943. Operating conditions for optimum behavior of a continuous counter-current, counter-gravity extraction plant. Unpublished Ph. D. thesis. Iowa State College Library, Ames, Iowa.

THE MORPHOLOGY AND GENESIS OF PRAIRIE SOILS DEVELOPED FROM PEORIAN LOESS IN SOUTHWESTERN IOWA¹

CURTIS EVAN HUTTON

From the Department of Agronomy, Iowa State College

A detailed study was made on five prairie soil profiles on the gently undulating uplands in southwestern Iowa. It included a study of the distribution pattern of the Peorian loess deposit and morphological, chemical, and physical studies of the prairie soils along two northwest-southeast traverses through the area.

The Peorian loess was shown to have a thickness of more than 100 feet near the Missouri River bluff. The thickness of the loess decreases along the northwest-southeast traverses. The rate of thinning along the traverses is very rapid near the bluff but becomes progressively less rapid with increasing distance from the bluff. Traverse No. 1, with its origin at the bluff adjacent to the wide river bottom in Monona County, extends in a northwest-southeast direction to southwestern Wayne County. The thickness of loess in southwestern Wayne County, a distance of 170 miles from the origin of the traverse, was shown to be 95 inches. The Missouri River bottom is proposed as the major source of supply of the loessial material, and a theory was advanced that it was deposited by winds which blew primarily from the northwest.

Morphological studies were made on the prairie soils along the traverses, and chemical and physical studies were made on five prairie soil profiles along Traverse No. 1. The soil series to which these profiles belong are the Monona silt loam, Marshall silt loam, Sharpsburg silty clay loam, Grundy silty clay loam, and Seymour silty clay loam. The soil series are developed in the direction of thicker to thinner loess deposits in the order named, and their geographical distribution is functionally related to the loess distribution pattern. The Monona silt loam is developed on the thick loess near the river bluff; the Seymour silty clay loam, on the thinnest loess along the traverse; and the Marshall, Sharpsburg, and Grundy series are developed on deposits of intermediate thickness between the two extremes.

The degree of soil development of these soil series increases in the direction of Monona to Seymour. The mechanical analysis studies show the degree of horizon differentiation in the Monona silt loam to be very weak. The degree of horizon differentiation increases in intensity through the Marshall, Sharpsburg, and Grundy series and attains its greatest degree of differentiation in the Seymour series. The mechanical analysis data also indicate that there was a segregation of the loessial material

¹ Doctoral thesis number 905, submitted June 7, 1948.

during its deposition with the percentage of coarse-sized particles of the material below the solum, decreasing with distance from the river bluff. If the assumption is made that loess deposition was continuous over the entire area studied during the loess deposition period, it follows that the soil solum would have been deposited in a shorter period of time where the loess is very thick than where it is very thin. If the thickness of the solum is taken to be 40 inches, theoretically, the solum of the Monona soil, which is developed on a loess deposit of 600 inches, would have been deposited in about one-fifteenth of the time of loess deposition. The solum of the Seymour series, which is developed on a loess deposit of less than 95 inches, would have been deposited in about two-fifths of the time of loess deposition. The other series in this study would have values between these extremes. The idea was proposed that the length of time during which these soil series have been subject to weathering increases in the direction of Monona to Seymour. The soils along these traverses were shown to be functionally related to these two soil forming factors, time and parent material.

A partial total analysis of the silt and clay fractions of the Monona and Seymour series indicates that weathering has been most active in the Seymour series. The clay minerals of these two series are shown to be mixtures of the Montmorillonite-beidellite, Nontronite, and Illite types. Kaolinite is shown to be absent or present in only minor amounts. There is an indication that the clay minerals of the Seymour profile have been weathered more than those in the Monona profile. The difference observed is based on exchange capacities, differential thermal analyses, and total analysis of the clays. Base exchange and mechanical analysis data indicate that the soil forming processes most active in the development of the soils along Traverse No. 1 are (1) one of cationic eluviation, and (2) the formation and movement of colloidal material in the soil profile. The intensity of the soil forming processes increases in the direction of Monona to Seymour. These factors, combined with differences in time of soil formation and differences in parent material, have been the primary causes of the differences in the character of the soils along these traverses.

A COMPARISON INVOLVING THE NUMBERS OF, AND RELATIONSHIP BETWEEN TESTERS IN EVALUATING INBRED LINES OF MAIZE¹

KENNETH R. KELLER

From the Department of Agronomy, Iowa State College

There are differences of opinion among maize breeders on the kind of tester best suited to evaluate inbred lines of maize. The choice of a tester depends upon the use to be made of the lines. A suitable tester is one of such genetic constitution as to detect inherent differences in the combining ability of the lines. When two or more testers are used in evaluating the same group of lines, they may be compared by (1) their ability to similarly rank the lines and, (2) their within tester x line variances.

Experiments were conducted to investigate the relationship between the use of a related and an unrelated line as tester parent. A group of 98 individual F_2 plants from an F_2 population of the single cross I233 x ITE701 were selfed and top-crossed to the related and an unrelated single cross. The top-cross yield trials were conducted in separate experiments at the same location. There were striking differences in vigor between the testers as expressed by yield in bushels per acre with the unrelated single cross tester combinations exhibiting the greater yields. Correlation coefficients were computed between six agronomic characters recorded in each of the two experiments. Several of the correlation coefficients were significant but in general were too low to be of value for predictive purposes. The results from this investigation indicated that two tester parents did not give similar measures of combining ability in the ranking of the lines.

An additional study was made of the variability within each of the two single cross testers when crossed with the 98 individual F_2 plants. The Chi square test for homogeneity of variances for the various agronomic characters as measured by the two tester parents gave significant differences for all characters except yield in bushels per acre and per cent stalk lodging. Of the four characters which exhibited significant differences in variability, the larger variances for per cent stand, ear height grade, and per cent moisture in the grain at harvest were observed in the related tester combinations. Variability for per cent root lodging was greater in the unrelated tester top-crosses. In general, the two tester parents were approximately equal in their measure of variability of the lines being tested.

From frequency distributions for yield in these two tests a seriated sample of lines covering the yield range in each experiment was chosen

¹ Doctoral thesis number 893, submitted March 16, 1948.

for further study in each of the two years. The selected F_3 lines were crossed to each of four standard inbred lines in one year and to each of three inbred lines and an open-pollinated line in another year. These combinations were compared in replicated yield trials. The association between the top-cross performance of F_3 lines and the performance of their F_2 parents when crossed to related and unrelated testers was investigated. In general, the related and unrelated testers were of approximately equal value in measuring combining ability from the standpoint of variability. Correlation coefficients were computed between all combinations of testers in each of the two F_3 top-cross trials. The data for the two experiments indicated that testers do not give like measures of combining ability regarding rank. The tester parents did indicate equal ability in measuring inherent differences as measured by their tester \times line variances. These tests did not permit of a definite decision as to which of the two testers, related and unrelated, was the better. The results illustrated that inbred lines as tester parents react differently in combinations with the lines. This suggested the use of more than one tester in evaluating inbred lines of maize.

Single cross tests involving all possible combinations of n inbred lines were used to study the relative efficiency of a number of testers and replications. Within a group of n lines, tested in all combinations, the maximum information about a line A can be obtained by considering its average performance for the $n-1$ combinations. The remaining lines involved in the test may be considered as testers used to estimate the performance of line A . The results with $n-2$, $n-3$, etc., testers may be used to estimate the number of testers required to obtain a valid estimate of the performance of line A . Inferences drawn from these data are limited to the lines involved in the investigation.

Thirty-seven experiments involving all possible combinations of n inbred lines were available for this study. These experiments involved 152 different inbred lines tested during the period from 1929 to 1947. Since methods were not available for estimating components of variance from incomplete block designs, it was necessary to reanalyze all experiments as randomized complete block designs.

The mean squares and variance components for error, lines \times testers, and lines were computed for each experiment. Unbiased estimates of the ratio of the variance components for lines \times testers and lines were also computed. Unweighted arithmetic means were used in estimating mean unbiased estimates for line \times tester and line components. These values are estimates of σ_{LT}^2 and σ_L^2 and were used in predicting the combining ability of the best inbred lines as determined from top-cross tests. Formulas were used for computing the average gain in combining ability due to the selection of the apparently best instead of a random line from a sample of n lines. The data indicate that the gain in genetic advance beyond the use of eight to ten inbred line testers is very slight. Using a similar approach for a constant number of lines, it was found that the gain in genetic advance beyond the use of three replications was small.

POLYGENIC INHERITANCE OF FRUIT SIZE IN RED PEPPER (*CAPSICUM FRUTESCENS* L.)¹

IAN KHAMBANONDA

From the Department of Genetics, Iowa State College

Two varieties of red pepper, Red Chili (P_1) with small elongated fruit and Sunnybrook (P_2) with large oblate fruit, were crossed, and without selection, the hybrids were selfed through the fourth filial generation. In experimental field tests, plants of the parental populations and of all hybrid generations were grown at the same time. Five fruits were harvested from each plant for measurements of length, width, shape (index ratio of length to width), green weight, and dry weight, which were the polygenic characters chosen for investigation.

Correlations, means, and variances of the characters were calculated on arithmetic and logarithmic bases. Variations of the non-segregating P_1 , P_2 , and F_1 generations were taken as environmental effects for estimating genotypic variances of F_2 , F_3 , and F_4 . The regression of F_4 on F_3 progeny means measures heritability of phenotypic differences of F_3 progenies, and the coefficient is used in determining genetic variances of segregating generations. The trend of generation means, the genotypic, and the genetic variances were compared with theoretical genetic expectations in selfed generations formulated with assumptions of various types of gene action, from which inferences on nature of the polygenes were made.

FRUIT LENGTH AND WIDTH

Results of statistical analyses confirm the supposition that length and width of fruit are largely expressions of shape and weight factors. Correlation studies of the characters show the existence of genes for shape. The extremely transgressive segregation of fruit length suggests that it is not inherited as such but as a component of shape. It is unlikely that genes control length and width of fruit *per se*; and even if length and width genes were present, they would cause only minor deviations after shape manifestations have been accounted for.

FRUIT SHAPE

By logarithmic transformations of data, the environmental variations of shape indices in P_1 , P_2 , and F_1 become equal, and therefore can be considered multiplicative. It is believed that genotypic variations in F_2 , F_3 , and F_4 are also multiplicative. Trimodal logarithmic distributions of fruit shapes in segregating generations indicate a major gene difference. The distribution frequencies can be sharply divided into two groups,

¹ Doctoral thesis number 902, submitted June 4, 1948.

which fit the monohybrid ratios in case of self-fertilization. When modal values are used to evaluate genotypes, the oblate (00) shape index is 1.15 (log .06), the heterozygote (0o) 1.51 (log .18), and the elongated (oo) 3.43 (log .54), oblate being partially dominant to elongated. The variances contributed by this gene pair alone approximate the observed genotypic variances, implying only one gene pair for shape segregation. The discrepancy between the homozygous genotypes and the corresponding parental types is attributed to genetic substrate dissimilarities and environmental modifications.

GREEN WEIGHT OF FRUIT

Fruit weights in non-segregating populations vary exponentially with means, which leads to a conclusion that environmental variations are multiplicative. Positive skewness of F_2 , F_3 , and F_4 distributions may be explained by either dominance or epistasy of small weight, or multiplicative effects of genes. However, since the generation means, $F_1 = \log 1.771$, $F_2 = \log 1.758$, $F_3 = \log 1.694$, and $F_4 = \log 1.673$, tend to decrease, which is characteristic of gene action with excess of dominance or epistasy of large weight, the skewness is ascribed to multiplicative effects of genes rather than dominance or epistasy of small size. Thus, a deduction may be drawn that actions of weight genes are multiplicative and preponderantly dominant or epistatic for large fruit.

With a logarithmic scheme of analysis, heritability of F_3 progeny means is 64 per cent. An examination of variances reveals some evidences of linkage and epistasy. Substrate factors seem to affect expressivity of the genes. It is estimated that the minimum number of genes for fruit weight differences in this pepper cross is between twenty and thirty-three.

DRY WEIGHT OF FRUIT

Dry weight and green weight of fruits within parental and hybrid populations are strongly correlated. Genetic analyses of the two weights give identical results and conclusions regarding the number and properties of genes. Both characters must be manifestations of the same genetic factors. With the regression method, it is found that 58 per cent of phenotypic variations of dry fruit weight between F_3 progenies is genetic.

The curvilinear association of dry and green weights between generation means is interpreted to mean that the multiplicative action of genes is expressed in the weight of dry matter of the fruit as well as in the water content, which increases in percentage with size of fruit.

PROPERTIES OF KERNELS OF INTEGRAL EQUATIONS WHOSE ITERATES SATISFY LINEAR RELATIONS¹

CARL ERIC LANGENHOP

From the Department of Mathematics, Iowa State College

In the Fredholm integral equation

$$u(x) = f(x) + \lambda \int_a^b K(x,t) u(t) dt$$

the function $K(x,y)$, which will be supposed real, is called the kernel of the equation. In the theory of such integral equations there are defined the iterated kernels

$$K_1(x,y) = K(x,y),$$

$$K_2(x,y) = \int_a^b K_1(x,t) K(t,y) dt,$$

and, in general,

$$K_n(x,y) = \int_a^b K_{n-1}(x,t) K(t,y) dt.$$

(In this thesis integration is in the sense of Lebesgue.)

The main result of this thesis is concerned with kernels and their iterates and can be stated as follows: If $K(x,y)$ is bounded and measurable over the square $a \leq x, y \leq b$, and if the iterated kernels satisfy the relation

$$(1) \quad a_1 K_1(x,y) + a_2 K_2(x,y) + \dots + a_n K_n(x,y) \equiv 0, \quad a_1 \neq 0,$$

over this square, then $K(x,y)$ can be written in the form

$$(2) \quad K(x,y) = \sum_{i=1}^N u_i(x) v_i(y)$$

for $a \leq x, y \leq b$.

This result follows when one notes that $K(x,y)$ is a solution of an integral equation

$$K(x,y) = \int_a^b H(x,t) K(t,y) dt$$

where $H(x,y)$ is a linear combination of the iterates of $K(x,y)$. $H(x,y)$

¹ Doctoral thesis number 915, submitted June 7, 1948.

is bounded since $K(x, y)$ is, and using Bessel's inequality, one shows that there can be only a finite number of y 's yielding linearly independent $K(x, y)$'s considered as functions of x .²

For kernels for which $\int_a^b K(t, t) dt$ exists the preceding theorem is

used to show that only bounded kernels of the form (2) can have their Fredholm determinant $D(\lambda)$ and Fredholm first minor $D(x, y; \lambda)$ being polynomials in λ of the same degree. This follows readily when one shows that the coefficient of λ^{n+1} in $D(x, y; \lambda)$ can be written as

$$(3) \quad A_n K_1(x, y) - n A_{n-1} K_2(x, y) + n(n-1) A_{n-2} K_3(x, y) + \dots \\ + (-1)^n n! K_{n+1}(x, y)$$

where A_r is the coefficient of λ^r in $D(\lambda)$. $D(x, y; \lambda)$ and $D(\lambda)$ being polynomials in λ of the same degree, say n , implies that the expression (3) is identically zero and that $A_n \neq 0$.

The theorem is also used to prove that for a bounded continuous symmetric kernel, if either $D(\lambda)$ or $D(x, y; \lambda)$ is a polynomial in λ , then $K(x, y)$ must be of the form (1). (This result also follows from a known expansion of a symmetric kernel in terms of the characteristic solutions and the fact that the number of these solutions is finite if $D(\lambda)$ is a polynomial.) For kernels of the special form (1) it is known that $D(\lambda)$ is a polynomial, so some of the theorems of this thesis provide a partial converse of this fact.

If one defines the matrix C with elements

$$c_{ij} = \int_a^b v_i(t) u_j(t) dt,$$

then, in general,

$$K_n(x, y) = U(x) C^{n-1} V^T(y)$$

where $U(x)$ and $V(y)$ are the row matrices

$$(u_1(x), u_2(x), \dots, u_N(x)), (v_1(y), v_2(y), \dots, v_N(y)),$$

respectively. If the $u_i(x)$ are all linearly independent, as they would be when properly chosen, then the relation (1) is equivalent to the matrix equation

$$a_1 I + a_2 C + \dots + a_n C^{n-1} = 0.$$

If $K(x, y)$ satisfies the relation

$$(4) \quad K_2(x, y) \equiv K(x, y),$$

²This part of the proof is very similar to the reasoning used by Bocher in proving that the index of any characteristic constant of a bounded kernel is finite. M. Bocher, *An Introduction to the Study of Integral Equations*. Cambridge University Press, London, 1909, p. 56.

the kernel is designated as idempotent. For such a kernel the matrix C satisfies

$$C = I,$$

so that

$$\int_a^b v_i(t) u_j(t) dt = \delta_{ij}.$$

It follows immediately then that $\int_a^b K(t,t) dt$ for an idempotent kernel

must be a positive integer or zero in the trivial case $K(x,y) \equiv 0$.

Functions satisfying (4) have arisen in connection with a special type of Markoff stochastic process concerning which Blackwell³ has proven a general theorem showing how the range of each variable is broken up into disjoint sets A_n over each of which $K(x,y)$ is a function of y alone. The remainder of the present thesis is devoted to an alternative proof of part of Blackwell's result.

³ "Idempotent Markoff Chains," *Annals of Mathematics*, Series 2, 43:560-67. (1942.)

STRATIFICATION IN SURVEY SAMPLING¹

CLIFFORD JOSEPH MALONEY

From the Department of Statistics, Iowa State College

In the practical application of the principle of stratification to survey sampling, it is common to have information as to the distribution of the members of the population to be sampled on the basis of each of two or more criteria, without having information on the joint distribution. In this situation, a number of practical procedures for obtaining the sample and making use of all the relevant information are available and have been used. It has not always been recognized, perhaps, that there must necessarily be some loss of precision by any such scheme as compared to sampling with complete stratification.

The present study consists of an examination of the extent of such loss and a practical scheme—not known to have been actually employed—for carrying out such sampling. The argument rests on a chain of four theorems. A fifth theorem from the literature provides some measure of the relative efficiency of sampling, when only the marginal distributions are employed, compared to that of sampling at random or sampling with complete stratification.

The first two theorems, while simple, are extremely general. The hypotheses in both cases are (1) that the expected value of the number of sample elements taken from the cells of the multiply-stratified population be independent of the value of the sampled character; (2) that the expected value of the character be independent of the manner in which the sample is distributed into the cells of the population. The first theorem then establishes that the expected value of the sample mean depends only on the first moment of the population. The second theorem shows that the variance of the sample mean depends only on the first two moments in the population. Both depend also on the numbers selected from the several strata and the number in the several strata.

A corollary to the first theorem asserts that, if (1) the expected value of the sample cell proportions are equal to the population cell proportions, and if (2) the expected value of each element in the sample is equal to the population mean for the cell from which selected, then the expected value of the sample mean is equal to the population mean. A corollary to the second theorem shows that under the same conditions plus the condition that (3) the value of the characters of elements selected from different cells are uncorrelated, then the variance of the sample mean is equal to that obtained under complete stratification plus a quantity, L , which depends on the population cell means and on the distribution of the sample cell numbers.

¹ Doctoral thesis number 899, submitted June 3, 1948.

In the sampling scheme which forms the subject of this study, the sample is to be selected at random, subject only to the restriction that the sample marginal proportions are to be equal to the population marginal proportions. Hence, the two theorems are at once applicable. Two of the three conditions necessary to make the two corollaries applicable are evidently satisfied. It remains to show that the expected values of the sample cell proportions are equal to the population cell proportions. The solution obtained to this question is an asymptotically valid one, closely akin to that obtained in the related chi-square problem by Karl Pearson.

If the sample cell numbers were freed of the marginal conditions and subject only to the requirement on the total number, then it is well known that the allocation of sample numbers to the cells of the population would follow the multinomial distribution. The effect of the marginal conditions is to replace the full multinomial distribution by the conditional distribution of those terms of the full distribution which satisfy the restrictions, which are all of the form of linear restraints on the cell numbers. Hence, in the discussion, advantage is taken of the fact that the multinomial distribution is asymptotically normal, and that the multivariate normal distribution possesses the reproductive property to replace the original set of variables—the sample cell numbers—by the marginal totals and enough of the sample cell numbers to make the transformation non-singular. The approximating normal distribution of these retained sample cell numbers is then obtained. The quantity, L , by which the variance of the sample means obtained by this method of sampling exceeds that of sample means obtained by complete stratification, is reduced by this transformation to the expected value of a linear combination of the retained sample cell numbers, where the coefficients are linear combinations of population strata means.

The third and fourth theorems establish that the conditional distribution of the retained sample cell numbers is identical with the least squares estimates of these populational cell numbers, where sampling is random and the least squares normal equations arise through the action of the marginal restrictions. This result affords a practical technique for drawing samples: (1) draw a single random sample, (2) adjust the sample cell numbers to the marginal restrictions by least squares, and (3) fill up any deficient cells by additional drawings.

The actual evaluation of the quantity, L , requires a knowledge of the population cell proportions and of the cell means, and the solution of a system of simultaneous linear equations of an order equal to the number of independent cell frequencies. While the matrix of this system of equations is symmetrical and possesses a strong pattern in the elements, no simple explicit inversion of it was found. A reduction of its order was obtained by matrix methods, and a detailed discussion of the determinant of the matrix was carried out. The nature of the polynomial value of the determinant was ascertained, leading to a method of calculation which might prove useful in machine evaluation. A first and second approximation to the exact determination were also devised.

SOLUBLE MANGANESE AS A FACTOR AFFECTING THE GROWTH OF VARIOUS LEGUMES IN CULTURE SOLUTIONS AND IN ACID SOILS¹

HAROLD DONALD MORRIS

From the Department of Agronomy, Iowa State College

Several legumes were grown in culture solutions of varying manganese levels to determine the minimum concentrations of manganese necessary for injury. The species differed greatly in their tolerance to manganese. The concentrations of manganese found to be injurious to the various legumes ranged from 1 to 10 p.p.m. The legumes ranked in order of their sensitivity to manganese toxicity were: lespedeza, sweet clover, soybeans and cowpeas, and peanuts. The manganese toxicity symptoms exhibited by the legumes also differed greatly. The toxicity symptoms were confined almost entirely to the leaves.

The legumes differed greatly in the amounts of manganese absorbed from culture solutions containing identical concentrations of manganese. Cowpeas absorbed the largest quantities of manganese, soybeans and lespedeza intermediate amounts, and sweet clover and peanuts the smallest amounts. The manganese concentration of the leaves was several times that of the stems. The tolerance of legumes to manganese was apparently determined by two factors: (1) the quantity of manganese absorbed by the plant, and (2) the tolerance to large amounts of manganese within the plant.

Two strains of Korean lespedeza used in the experiment differed significantly in their tolerance to manganese toxicity. The difference in tolerance of the two strains to manganese toxicity was found to be related to their relative growth under acid and alkaline soil conditions. The strain which showed the least tolerance to manganese grew relatively poorer under acid soil conditions and relatively better under alkaline soil conditions.

An increase in the calcium concentration of the culture solution from 12 to 60, or to 300 p.p.m. was ineffective in reducing manganese toxicity of lespedeza. At the highest calcium level there was some indication that manganese toxicity was increased. No alleviation of manganese toxicity was obtained by increasing phosphorus in the nutrient solution from 2 to 20 p.p.m.

Increasing the concentration of iron from 0.2 to 1.0 p.p.m. in the nutrient solution resulted in greatly reduced toxicity from a given concentration of manganese. Increasing the iron in solution above 1.0 p.p.m. resulted in reduced growth of lespedeza regardless of the manganese

¹ Doctoral thesis number 878, submitted December 15, 1947.

concentration. Marked differences in growth and toxicity symptoms were obtained at identical iron-manganese ratios, with different total amounts of iron and manganese indicating that the iron-manganese ratio is not the primary factor controlling toxicity. The beneficial effect of iron in reducing manganese toxicity was due to a decrease in manganese absorbed by the plant rather than an increase in iron absorption. Iron deficiency and manganese toxicity symptoms of soybeans were not identical as has been claimed by other investigators.

The exchangeable and water-soluble manganese concentrations of twenty-five naturally acid soils were determined. Concentrations of exchangeable manganese varied from 1 to 638 p.p.m. Water-soluble manganese in 1:2 soil-water extracts ranged from none to 6.3 p.p.m. expressed on an oven-dry soil basis. The average concentration of water-soluble manganese of the most acid soils was considerably higher than that of the less acid soils. Soils containing high concentrations of water-soluble manganese were either more acid than pH 5.20 or contained relatively large amounts of exchangeable manganese. Soil solutions of soils upon which plants made very poor growth and exhibited extreme manganese toxicity symptoms contained concentrations of manganese greatly in excess of those found to be toxic to legumes in culture solutions.

Lespedeza and sweet clover grown on several acid soils exhibited toxicity symptoms identical with those obtained when these legumes were grown in culture solutions containing toxic concentrations of manganese. Where manganese toxicity symptoms were evident the plant contained large amounts of manganese, and relatively high concentrations of water-soluble manganese were present in the soil. When sweet clover or lespedeza contained more than 400 p.p.m. manganese, toxicity symptoms were apparent, and the severity of these symptoms and the reductions obtained in yields were proportional to the concentration of manganese in the plant.

Applications of calcium carbonate were beneficial to plant growth on acid soils containing high amounts of water-soluble manganese. This beneficial effect was due, at least in part, to the reduction of soluble manganese in the soil brought about by the increase in pH. No beneficial effect was derived from calcium carbonate on acid soils containing very low concentrations of water-soluble manganese.

Applications of calcium sulfate to acid soils were detrimental because of the increased water-soluble manganese in the soil and a corresponding increase in the manganese content of the plant brought about by the treatment rather than failure to supply an available form of calcium. Calcium sulfate increased the soil acidity in all cases.

Applications of phosphate as high as 1,500 pounds P_2O_5 per acre were ineffective in reducing manganese toxicity of legumes on certain acid soils. Increases in yield obtained from the high phosphate treatments were due to the additional phosphorus supplied rather than to any decrease in the water-soluble manganese content of the soil.

ORIENTATION AND CLEAVAGE OF SOME SUBSTITUTED DIBENZOTHIOPHENES¹

JOHN FRANCIS NOBIS

From the Department of Chemistry, Iowa State College

The study of dibenzothiophene chemistry was initiated in these laboratories some years ago by Jacoby² and was continued to some extent by Avakian.³ A renewal of interest in dibenzothiophene chemistry was stimulated by some war research problems dealing with the preparation of antimalarial and antituberculous compounds. During the course of this work a number of new dibenzothiophene compounds was prepared and these compounds were of particular interest in medicinal organic chemistry. It was also necessary to prepare some previously reported compounds, and new procedures and new constants have been listed for several of these. A literature survey of the known derivatives of dibenzothiophene has been included.

Certain dibenzothiophenylsilanes were prepared in order to study the stability of the C-Si bonds. This stability study was made by determining the percentage of cleavage products obtained when the compounds in question were treated with anhydrous hydrogen chloride in refluxing acetic acid solution for fifteen hours. Some other new organosilanes were also prepared for cleavage studies.

The author was motivated by the same war research problems to prepare a series of 2,5-dimethylpyrroles and 2-methyl-5-phenylpyrroles.

The method of Gilman and Jacoby⁴ for the preparation of 2-acetyldibenzothiophene was modified slightly during the course of this research and a pure yield of 45 per cent, not previously reported by these researchers, was obtained. 2-Acetyldibenzothiophene oxime⁴ was treated with phosphorous pentachloride and the resulting acetamino compound hydrolyzed to give a 72 per cent yield of 2-aminodibenzothiophene. 2-Aminodibenzothiophene was also prepared in 91.5 per cent yield by catalytic reduction of 2-nitrodibenzothiophene. 2-Aminodibenzothiophene-5-dioxide, m.p. 278°-280°, and 2-nitrodibenzothiophene-5-dioxide⁵ were prepared in 87 per cent yields by oxidation of the parent compounds with hydrogen peroxide.

2-Hydroxydibenzothiophene, was prepared from 2-aminodibenzothiophene, and an unsuccessful attempt was made to prepare this phenol by fusion of 2-bromodibenzothiophene with sodium hydroxide.

2,8-Diacetyldibenzothiophene was prepared in 77 per cent yield

¹ Doctoral thesis number 897, submitted May 28, 1948.

² Jacoby, Doctoral Dissertation, Iowa State College, 1938.

³ Avakian, Doctoral Dissertation, Iowa State College, 1944.

⁴ Jour. Org. Chem. 3:108 (1938).

⁵ Cullinane, Davies, and Davies, Jour. Chem. Soc. p. 1435 (1936).

from 2-acetyldibenzothiophene in larger amounts and by a slightly different procedure than that reported by Burger and co-workers.⁶ Additional proof of structure of this compound was found by the preparation of 2,8-diacetaminodibenzothiophene, m.p. 303°, in 93 per cent yield by a Beckmann rearrangement of 2,8-diacetyldibenzothiophene dioxime and 2,8-diaminodibenzothiophene, m.p. 199.5°–200°, in 76 per cent yield by hydrolysis of the diacetamino compound. Mixed melting point determination with authentic specimens, prepared by nitration of 2-nitrodibenzothiophene followed by catalytic reduction and acetylation, were not depressed. Courtot⁷ has reported a melting point of 237° for the diacetamino compound and Burger and co-workers⁶ listed a melting point of 253°. Courtot listed the melting point of 2,8-diaminodibenzothiophene as 178° and Burger and co-workers recorded it at 193°. In some recent studies by Neumoyer and Amstutz⁸ on 2,8-diaminodibenzothiophene, new melting points are also recorded that agree with those found here.

Neumoyer and Amstutz⁸ reported that they were unable to oxidize their 2,8-diacetamino compound to the corresponding 5-dioxide. It was found that 2,8-diacetaminodibenzothiophene could be oxidized to the 5-dioxide, m.p. 356°–357°, in good yields by the use of either hydrogen peroxide or hypochlorous acid. 2,8-Diaminodibenzothiophene-5-dioxide, m.p. 327°–328°, was obtained by hydrolysis of the diacetamino 5-dioxide.

4-Methoxydibenzothiophene-5-dioxide, m.p. 191°, was prepared by oxidation of 4-methoxydibenzothiophene with hydrogen peroxide.

It was noted that the observed orientation of the dibenzothiophene nucleus and the dibenzothiophene-5-dioxide nucleus is in excellent agreement with the predictions of the modern electronic theory of aromatic substitution. Since the chemistry of dibenzothiophene is analogous in many respects to the chemistry of the related heterocycle dibenzofuran, a comparison of the melting points of similar compounds was included. The following generalizations were apparent. First of all, it seems that most dibenzothiophene derivatives containing the same functional group in the analogous position to the dibenzofuran derivatives melt higher. Secondly, the melting points of the substituted dibenzofuran compounds increase from the 1-position to the 2-position to the 3-position with the melting point of the 4-isomer usually lower than that of the 3-isomer. This same phenomenon seems to be borne out in the dibenzothiophene series.

The organosilicon derivatives of dibenzothiophene were prepared in the conventional manner⁹ from the appropriate dibenzothienyllithium compounds and the trisubstituted silicon halides. The preparation of all dibenzothienylsilanes involved the difficulty of separation of the unreacted dibenzothiophene. The 5-dioxides of the compounds were prepared in excellent yields by oxidation with hydrogen peroxide.

⁶ Burger, Wartman, and Lutz, *Jour. Amer. Chem. Soc.* 60:2628 (1938).

⁷ Courtot and Pomonis, *Compt. rend.*, 182:893 (1926).

⁸ *Jour. Amer. Chem. Soc.* 69:1920 (1947).

⁹ Clark, Doctoral Dissertation, Iowa State College, 1946.

4-Trimethylsilyldibenzothiophene, b.p. 215°/20 mm., was prepared in 87 per cent yield from 4-dibenzothieryllithium³ and trimethylsilyl chloride. When this silane was treated with anhydrous hydrogen chloride an 87 per cent yield of dibenzothiophene was obtained. A quantitative recovery of 4-trimethylsilyldibenzothiophene-5-dioxide, m.p. 146°, prepared in 42 per cent yield from 4-trimethylsilyldibenzothiophene and hydrogen peroxide, was obtained when this dioxide was treated with hydrogen chloride. Apparently, the formation of the 5-dioxide stabilized the molecule to a considerable extent. Additional evidence of this stability was noted by the fact that it was possible to prepare a mononitro derivative of this dioxide, m.p. 223°.

4-Triphenylsilyldibenzothiophene, m.p. 193°, was prepared in 6.8 per cent yield from 4-dibenzothieryllithium and triphenylsilyl chloride. The dioxide, m.p. 212°, was obtained in 93 per cent yield. 4-Triphenylsilyldibenzothiophene was not cleaved by hydrogen chloride but a mixture of cleavage products was obtained when the compound was treated with bromine. Marshall¹⁰ also observed that the trimethylsilyl group would cleave more easily than the triphenylsilyl group when attached to the same nucleus.

2-Triphenylsilyldibenzofuran, m.p. 124°, was prepared in 8.7 per cent yield from 2-dibenzofuryllithium¹¹ and triphenylsilylchloride. The 4-isomer could not be prepared.

Triphenyl- β -styrylsilane, m.p. 146°, triphenylphenylethynylsilane, m.p. 96°–98°, triphenyl- α -chloroethylsilane, m.p. 129°, triphenyl- β -chloroethylsilane, m.p. 124°, and triphenylethylsilane¹² were prepared by sequences of reactions which started with the appropriate organolithium compounds. Triphenyl- α -chloroethylsilane was also prepared from triphenylethylsilane and sulfuryl chloride. This compound did not react with sodium hydroxide nor magnesium.

Triphenyl- β -styrylsilane gave 21 per cent hexaphenyldisiloxane when treated with hydrogen chloride. Triphenylphenylethynylsilane cleaved easily with hydrogen chloride to give 67 per cent acetophenone and 32 per cent hexaphenyldisiloxane. The C-Si bond was probably broken first to give triphenylsilyl chloride and phenylacetylene. The phenylacetylene then would add hydrogen chloride to give dichloroacetophenone. The admixture of water to the cleavage products and subsequent reaction would account for the isolation of the acetophenone and hexaphenyldisiloxane.

Trimethyl-*o*-anisylsilane, b.p. 91°/15 mm., trimethyl-*p*-anisylsilane, b.p. 220°/740 mm., and trimethyl-*p*-bromophenylsilane⁹ were prepared from trimethylsilyl chloride and the corresponding organolithium compounds. Trimethyl-*p*-hydroxyphenylsilane could not be prepared by oxidation of trimethyl-*p*-lithiophenylsilane, by reaction of trimethylsilyl chloride with lithium *p*-lithiophenoxide, nor by cleavage of trimethyl-*p*-

¹⁰ Doctoral Dissertation, Iowa State College, 1948.

¹¹ Gilman, Langham, and Willis, Jour. Amer. Chem. Soc. 62:346 (1940).

¹² Marsden and Kipping, Jour. Chem. Soc. 93:209 (1908).

anisylsilane with sodium in pyridine.¹³ The corresponding *o*-hydroxyphenylsilane could not be isolated from similar attempted preparations. The course of these reactions was followed by means of Color Test I. It was found that the trimethylhydroxyphenylsilanes probably existed in solution but were unstable and cleaved during the attempted isolation. Phenol was the only phenolic material isolated from these reactions.

1-(*p*-Bromophenyl)-2-methyl-5-phenylpyrrole, m.p. 119°, 2-(2-methyl-5-phenylpyrrol-1)-pyridine, m.p. 94.5°, 1-(*p*-carboxyphenyl)-2-methyl-5-phenylpyrrole, m.p. 210°, and 8-(2-methyl-5-phenylpyrrol-1)-6-methoxyquinoline, m.p. 139°, were prepared by condensation of the appropriate amines with phenacylacetone.

¹³ Prey, Ber., 76B:156 (1943).

BACTERIAL METABOLISM OF GLYCINE AND ALANINE¹

DAVID PARETSKY

From the Department of Bacteriology, Iowa State College

THE INTERMEDIARY METABOLISM OF GLYCINE

Although glycine is the simplest of the amino acids, little is known about its mode of dissimilation by bacteria. The purpose of these investigations is to examine and determine the mechanism of the bacterial oxidative dissimilation of glycine. For the purpose of this investigation a species of *Achromobacter* was employed. These organisms metabolize glycine in a manner as yet unreported in the literature. The equation for the overall reaction is



The mechanism of the dissimilation is more complex than the equation indicates.

It is proposed that hydrogen peroxide is formed in the initial stage of the oxidation in the manner postulated by Krebs (1936). It is decomposed by peroxidase present in the bacteria and so participates in metabolic reactions. The importance of hydrogen peroxide in intermediary metabolism is discussed. Through the action of peroxidase, hydrogen peroxide may oxidize metabolic products which are otherwise not oxidizable by the cells. By such action hydrogen peroxide may prevent the accumulation of products which are normally toxic to cells. One such product is formaldehyde.

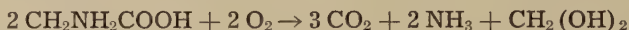
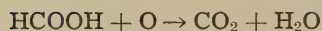
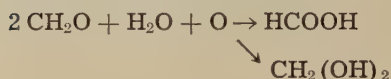
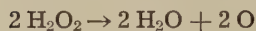
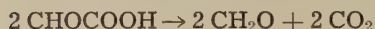
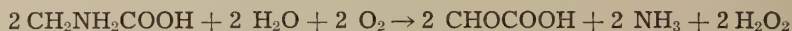
Although there has been much work done on the role of formaldehyde in photosynthesis, the problem is still controversial. In the present studies formaldehyde has been isolated (dimedon derivative) as an intermediate during the bacterial dissimilation of glycine. Sensitive tests fail to reveal the presence of formaldehyde as a final product of metabolism; it is apparently further metabolized by the bacteria. Evidence is presented to suggest that the formaldehyde probably undergoes a partial dismutation to formic acid and methylene glycol. Formic acid is oxidized to carbon dioxide and water. Methylene glycol is hydrated formaldehyde and in dilute aqueous solution formaldehyde actually exists as methylene glycol and lacks the carbonyl structure. It is proposed that methylene glycol is polymerized by the bacteria to higher carbohydrate-like compounds. The analytical evidence indicates that some of the synthesized extracellular material is of a ketopentose nature, and derivatives of substituted phenylhydrazine compounds have been prepared of

¹ Doctoral thesis number 888, submitted March 12, 1948.

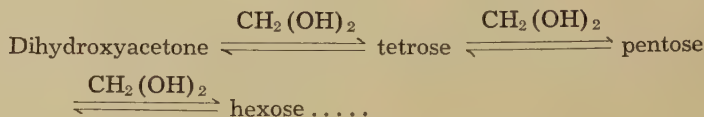
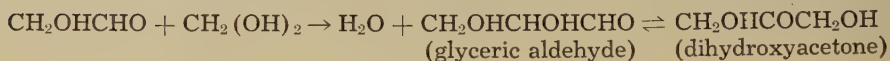
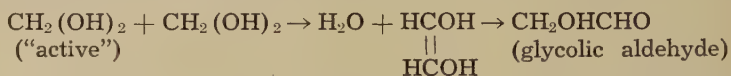
this material. Some of the synthesized intracellular material may act as a reducing carbohydrate after acid hydrolysis of the bacteria.

The theory is presented that the methylene glycol resulting from the oxidative dissimilation of glycine is in a "biologically active" form, and as such participates in the synthesis of carbohydrates by the mechanisms proposed by Küster and Schoder (1924), Orthner and Gerisch (1933), Kusin (1935), and Langenbeck (1942).

The following mechanism of oxidative dissimilation of glycine is proposed:



Methylene glycol may be polymerized to higher carbohydrates by the following type of mechanism:



THE BACTERIAL SYNTHESIS OF ALANINE

The synthesis of alanine by *Aerobacter aerogenes* was investigated. It was found that under the experimental conditions described, carbon dioxide is not required by non-proliferating cells for the synthesis of alanine from pyruvic acid and ammonium chloride. More alanine was found when the reactions were conducted under anaerobic conditions than under aerobic conditions.

Cell-free enzyme preparations were made from *Aerobacter aerogenes*. These preparations could utilize the ammonium ion and pyruvic acid for the synthesis of alanine. As in the case of intact cells, the necessity for carbon dioxide in the synthesis of alanine could not be demonstrated.

Approximately 25 per cent of the added pyruvate was recovered as alanine. Since the reaction



is endergonic, the energy for the synthesis is probably derived from a coupled reaction in which part of the pyruvate is dissimilated. The necessity for phosphate makes it likely that a phosphorylated intermediate is involved in the synthesis of alanine by the cell-free enzyme system.

LITERATURE CITED

KREBS, H. A.

1936. Metabolism of amino acids and related substances. *Ann. Rev. Biochem.* 5: 247-70.

KUSIN, A.

1935. Über die katalytische Wirkung von Monosen auf die Formaldehyde-Kondensation. I. *Ber. dtsh. chem. Ges.* 68: 619-24.

KÜSTER, W. AND F. SCHODER

1924. Über das Entstehen von Sorbose bei der Kondensation des Formaldehyde. *Z. physiol. Chem.* 151: 110-31.

LANGENBECK, W.

1942. Die Formaldehydkondensation als organische Autokatalyse. *Naturwiss.* 30: 30-34.

ORTHNER, L. AND E. GERISCHE

1933. Über die Primarstufen der Kondensation von Formaldehyd. *Biochem. Z.* 259: 30-52.

THE PHYSIOLOGICAL ACTION OF THIAMINE ANALOGUES IN THIAMINE DEPENDENT SYSTEMS¹

JOSEPH C. PICKEN, JR.

From the Department of Chemistry, Iowa State College

The use of structural analogues of naturally occurring, biologically active compounds, in the study of the physiological action of the natural compounds, has become a well-established and useful tool in biochemical research. The extension of this principle to the systematic structural modification of the active analogue molecules themselves, and the study of the effects of these on the action of the natural compounds, adds another effective and informative method for this type of study.

In thiamine and thiamine-enzyme chemistry, isolated analogue-thiamine antagonisms and interrelationships have been established for several different thiamine analogues characterized by minor modifications of the thiamine molecule. Systematic structural modifications of the analogue molecules themselves, for the purpose of investigating their mode of action, have been reported for only one of the active analogues, oxythiamine, in which the presence of the free hydroxyl group on the ethyl side chain of the thiazole moiety has been shown to be necessary for the inhibitory activity of oxythiamine.

Two new types of thiamine analogues, the benzyl-(3)-thiazolium and the amino alkyl-(3)-thiazolium, have been studied and certain ones found to be effective in influencing thiamine function in animal and microbial species. Among these, the *o*-aminobenzyl-(3)-4-methyl-5- β -hydroxyethylthiazolium analogue of thiamine is an inhibitor of rat growth; but also exerts a marked stimulatory effect on the growth of *Lactobacillus fermentum* 36. The *o*-aminobenzyl- and the γ -aminopropyl-(3)-4-methylthiazolium analogues of thiamine have been found to exert an inhibitory effect on the growth of *L. fermentum* 36.

The benzyl-(3)-thiazolium compounds investigated include the benzyl, *o*- and *p*-aminobenzyl, the *o*-, *m*-, and *p*-nitrobenzyl-(3)-4-methyl-5- β -hydroxyethylthiazolium analogues of thiamine, and the benzyl, *o*-aminobenzyl- and *o*-nitrobenzyl-(3)-4-methylthiazolium analogues of thiamine. Amino alkyl analogues include the γ -phthalimidopropyl- and the methyl-(3)-4-methyl-5- β -hydroxyethylthiazolium analogues of thiamine, and the γ -amino-propyl-, the γ -phthalimidopropyl- and the Δ -amino-*n*-butyl-(3)-4-methylthiazolium analogues of thiamine. All analogues were in the form of the usual chloride, bromide, or iodide salts typical of thiamine type compounds.

The effect of three of the analogues, the benzyl-(3)-4-methyl-5- β -hydroxyethylthiazolium chloride, *o*-aminobenzyl-(3)-4-methyl-5- β -

¹ Doctoral thesis number 877, submitted December 16, 1947.

hydroxyethylthiazolium iodide hydroiodide, and the *o*-aminobenzyl-(3)-4-methylthiazolium chloride hydrochloride, on the growth of weanling rats receiving suboptimal amounts of thiamine was investigated. The *o*-aminobenzyl analogue with the 5- β -hydroxyethyl side chain in the thiazole ring was the only analogue showing a definite inhibitory effect on the growth of the rats. Definite inhibitory responses were observed for this analogue with analogue-thiamine mole ratios from 12.5/1 to 400/1. A slight inhibitory response was observed at levels of 6.25/1. The results indicate that for the benzyl-(3)-thiazolium type analogues, the *ortho* amino group on the benzene ring, as well as the 5- β -hydroxyethyl group in the thiazole ring, are required for an inhibitory analogue.

The effects of representative compounds among the benzyl and alkyl-(3)-thiazolium analogues of thiamine were studied in relation to the thiamine and cocarboxylase stimulated growth of the bacterium, *L. fermentum* 36. The growth response in the presence of varying analogue concentrations of mole ratios of analogue to thiamine from 1/1 to 10,000/1 was measured by the relative turbidities of the test and control suspensions of the bacteria after 17 hours of growth.

All analogues, benzyl or alkyl, possessing the 4-methyl-5- β -hydroxyethylthiazole nucleus exerted a stimulatory effect on the growth of the *L. fermentum* 36. The *o*- and *p*-aminobenzyl analogues were observed to be particularly effective in the stimulation of growth, effecting 50 per cent stimulation at mole ratios of analogue to thiamine of 100/1. The thiazole moiety common to these analogues as well as to thiamine gave a 50 per cent stimulation at a mole ratio of 250/1, indicating that the two analogue molecules were exerting a stimulatory effect inherent to the analogues themselves. Two analogues containing the 4-methylthiazole nucleus were definitely inhibitory toward growth of the *L. fermentum* 36. The *o*-aminobenzyl- and the γ -aminopropyl-(3)-4-methylthiazolium analogues were quite effective as growth inhibitors, while the benzyl and *o*-nitrobenzyl analogues exhibited a definite stimulatory action. Blocking the amino group of the γ -aminopropyl analogue with a phthalimido group, or placing the amino group one carbon further away from the thiazole nucleus as in the Δ -amino-*n*-butyl analogue, negated the inhibitory effects of the aminopropyl analogue entirely. The importance of the free amino group three carbons removed from the thiazole nucleus for the inhibitory activity of this analogue has been clearly demonstrated.

An interesting and rather unique function was shown for the 5- β -hydroxyethyl group in the *o*-aminobenzyl analogues in that its presence in the *o*-aminobenzyl-(3)-4-methylthiazolium analogue makes the compound an effective stimulant for the *L. fermentum* 36, while its absence confers on this analogue a definite inhibitory function.

These active compounds, characteristic of the benzyl-(3)-thiazolium and the alkyl-(3)-thiazolium analogues of thiamine, represent new types of thiamine analogues that can enter into inhibitory or stimulatory relationships with thiamine. The studies made with the additional analogues of these two general groups which showed little or no activity,

coupled with the fact that all of these analogues represented marked structural modifications of the thiamine molecule, illustrate directly the prime importance of certain key functional groups and spatial configurations of the molecules that are necessary for analogue activity, and indirectly add evidence to the importance of these same functional groups and spatial configurations for the physiological action of thiamine itself.

The application of the bakers' yeast fermentation assay for thiamine to analogue-thiamine studies was investigated in great detail; however, the results indicated that this method of thiamine assay did not lend itself to studies of analogue-thiamine relationships.

SUBSTITUTED PYRIDINE AND QUINOLINE SULFIDES¹

MARY ALYS PLUNKETT

From the Department of Chemistry, Iowa State College

In view of the recent interest which has developed in physiologically significant sulfur-containing compounds and the importance of heterocyclic nuclei in compounds possessing physiological activity, some pyridine and quinoline sulfides were prepared as potential chemotherapeutic agents.

The first group of compounds prepared were quinoline or substituted quinoline sulfides having alkylaminoalkyl side chains. These sulfides were made by condensing an active chloroquinoline with a sodium alkylaminoalkyl mercaptide; by condensing a sodium quinoline mercaptide with an alkylaminoalkyl chloride; or by treating an active chloroquinoline with an isothiuronium salt and subsequently decomposing the complex with base. The compounds were isolated in most cases as the hydrochloride since the free bases proved to be unstable on distillation. The compounds synthesized in this group include: 2-quinolyl β -diethylaminoethyl sulfide hydrochloride, m.p. 192°–193°C.; 2-quinolyl γ -diethylaminopropyl sulfide hydrochloride, m.p. 141°–142°; 4-methyl-2-quinolyl β -diethylaminoethyl sulfide dihydrochloride, m.p. 216°–217°; 4-methyl-2-quinolyl γ -diethylaminopropyl sulfide dihydrochloride, m.p. 199°–200°; 6-methoxy-2-quinolyl β -diethylaminoethyl sulfide dihydrochloride, m.p. 168°–170°; 4-methyl-2-quinolyl β -(N-piperidyl)ethyl sulfide, m.p. 75°–76°; 4-methyl-2-quinolyl β -(N-morpholino)ethyl sulfide, m.p. 85°–85.5°; 6-methoxy-4-methyl-2-quinolyl γ -diethylaminopropyl sulfide hydrochloride, m.p. 200°–201°; 4-carboxy-2-quinolyl β -diethylaminoethyl sulfide hydrochloride, m.p. 240°–242°; 6-methoxy-4-quinolyl β -diethylaminoethyl sulfide dihydrochloride, m.p. 219°–220°; 7-chloro-4-quinolyl β -diethylaminoethyl sulfide dihydrochloride, m.p. 234°–235°; 2-quinolyl β -hydroxy γ -morpholinopropyl sulfide dihydrochloride, m.p. 198°–200°; picrate, m.p. 171°–172°; 2-quinolyl β -hydroxy γ -piperidylpropyl sulfide picrate, m.p. 188°–190°.

2-Mercapto-6-methoxyquinoline, m.p. 185°–187°, was prepared in 33 per cent yield from 2-chloro-6-methoxyquinoline and potassium hydrosulfide.

A group of sulfides containing the *p*-aminophenyl group was prepared. This group contained the following compounds: 2-quinolyl *p*-aminophenyl sulfide hydrochloride, m.p. 226°–228°; 6-methoxy-2-quinolyl *p*-aminophenyl sulfide, m.p. 117°–119°, hydrochloride, m.p. 233°–235°; 6-methoxy-4-quinolyl *p*-aminophenyl sulfide, m.p. 145°–146°; 4-carboxy-2-quinolyl *p*-aminophenyl sulfide, m.p. 334°.

2-(β -Chloroethyl)pyridine hydrochloride, m.p. 119°–121°, and 2-

¹ Doctoral thesis number 864, submitted August 5, 1947.

(γ -chloropropyl)pyridine hydrochloride, m.p. 109°–110°, were prepared by treating the corresponding alcohols with thionyl chloride. These compounds were used to synthesize the following group by reacting the pyridine chloride with the appropriate sodium mercaptide; β -(2-pyridyl) ethyl γ -diethylaminopropyl sulfide, b.p. 136°–139°/1 mm.; β -(2-pyridyl) ethyl β -diethylaminoethyl sulfide, b.p. 132°–135°/0.5 mm.; dihydrochloride, m.p. 156°–158°; β -(2-pyridyl) ethyl *p*-aminophenyl sulfide picrate, m.p. 142°–143°; γ -(2-piperidyl) propyl *p*-aminophenyl sulfide dihydrochloride, m.p. 228°–230°.

The physiologically active compound benadryl was used as a model for the preparation of diphenylmethyl β -(2-pyridyl) ethyl sulfide picrate, m.p. 146°–147°, hydrochloride, m.p. 152°–153°, which was made by treating a mixture of 2-(β -chloroethyl)pyridine hydrochloride and diphenylmethylisothiourea hydrobromide with sodium ethoxide and also by treating 2-(β -chloroethyl) pyridine with sodium diphenylmethyl mercaptide. Diphenylmethyl *p*-aminophenyl sulfide hydrochloride, m.p. 229°–230°, was prepared from sodium *p*-aminophenyl mercaptide and benzo-hydryl bromide.

The following group of miscellaneous sulfides was prepared: β -diethylaminoethyl γ -diethylaminopropyl sulfide dihydrochloride, m.p. 234°–235°; β -diethylaminoethyl β -(*N*-piperidyl) ethyl sulfide, b.p. 133°–135°/1.5 mm., dihydrochloride, m.p. 235°–237°; β -diethylaminoethyl β -(*N*-morpholino) ethyl sulfide, b.p. 147°–149°/2.5 mm., dihydrochloride, m.p. 199°–201°; γ -diethylaminopropyl β -(*N*-morpholino) ethyl sulfide, b.p. 142°–145°/1 mm., dihydrochloride, m.p. 216°–217°; 2-benzothiazyl β -diethylaminoethyl sulfide hydrochloride, m.p. 183°–184°; 2-quinolyl 2,4-dinitrophenyl sulfide, m.p. 160°–161°; 6-methoxy-4-methyl-2-quinolyl methyl sulfide, m.p. 104°–105°; 7-chloro-4-quinolyl 2-benzimidazole sulfide hydrochloride, m.p. 195°–196°; 7-chloro-4-quinolyl 2-(4',5'-diphenylimidazole) sulfide dihydrochloride, m.p. 166°–167°; 2-quinolyl 2-thiazolynyl sulfide hydrochloride, m.p. 189°–191°.

None of the sulfides reported has shown any significant therapeutic value.

In addition to the sulfides reported in this work, a group of nitrogen-containing silanes was made by reacting the appropriate *RLi* compound with silicon tetrachloride or with ethyl silicate. Compounds prepared by this method include the following: triphenyl (*p*-dimethylaminophenyl) silane, m.p. 144°–146°, hydrochloride, m.p. 227°–229°; diphenyl[di-(*p*-dimethylamino)phenyl]silane, m.p. 180°–181°; tri(*p*-dimethylaminophenyl)-phenylsilane, m.p. 171°–172°; tetra(*p*-dimethylaminophenyl)-silane, m.p. 234°–235°.

Triphenyl[2-(5-lithio)thienyl]silane was added to quinoline, to 6-methoxyquinoline and to 4,7-dichloroquinoline to give triphenyl[5-(2'-quinolyl)-2-thienyl]silane, m.p. 168°–170°; triphenyl[5-(6'-methoxy-2'-quinolyl)-2-thienyl]silane, m.p. 227°–228°; and triphenyl[5-(4',7'-dichloro-2'-quinolyl)-2-thienyl]silane, m.p. 200°–203°.

Triphenyl(phenylethynyl)silane, m.p. 95°–96°, was prepared by treating triphenyl(ethoxy)silane with phenylethynyllithium.

AVIAN RESPONSES TO COVER-WATER INTERSPERSION IN MARSHES OF CLAY AND PALO ALTO COUNTIES, IOWA¹

MAURICE W. PROVOST

From the Department of Zoology and Entomology, Iowa State College

There is some indication that distribution of open water among marsh covers is an environmental factor modifying the use of such covers for nesting by birds. Information on the various factors determining the distribution, constitution, and fragmentation of marsh covers was gathered in the Ruthven Area of Clay and Palo Alto counties, Iowa. This information is presented, and a comparative evaluation of these factors is advanced. The discussion of each environmental factor is based upon a consideration of its interrelationships with all factors in the total environment. The relationship of marsh water level to basin topography is stressed as an important matter that has so far attracted little attention and study. Water depth and muskrat cutting are described as the most important natural influences on cover-water interspersion. Interspersion is described as of the maze pattern, created usually by muskrats, or as of the ring pattern, created usually by excessive water depths for emergent plant survival.

The influence of cover type, water depth, and cover-water interspersion on nest distribution in marshes is discussed for twenty bird species whose nests were found and studied in 1942 and 1947. The largest samples were 389 nests of red-winged blackbird (*Agelaius phoeniceus arctolegus*), 190 nests of yellow-headed blackbird (*Xanthocephalus xanthocephalus*), 143 nests of coot (*Fulica a. americana*), 71 nests of pied-billed grebe (*Podilymbus p. podiceps*), 46 nests of prairie marsh wren (*Telmatodytes palustris dissaepetus*), and 45 nests of black tern (*Chlidonias nigra surinamensis*). Other species whose nests and nest sites were investigated were black-crowned night heron (*Nycticorax nycticorax hoactli*), American bittern (*Botaurus lentiginosus*), least bittern (*Ixobrychus e. exilis*), common mallard (*Anas p. platyrhynchos*), blue-winged teal (*Querquedula discors*), redhead (*Nyroca americana*), canvas back (*Nyroca valisineria*), ruddy duck (*Erismatura jamaicensis rubida*), marsh hawk (*Circus hudsonius*), king rail (*Rallus e. elegans*), Virginia rail (*Rallus l. limicola*), sora (*Porzana carolina*), Florida gallinule (*Gallinula chloropus cachinnans*), and Forster's tern (*Sterna forsteri*).

Factors modifying cover utilization are presented as residing in the cover, in the individual bird, and in the bird population. Cover affects nest distribution through the character of substrate it offers for nests of various structural characteristics. The individual nesting bird affects nest

¹ Doctoral thesis number 880, submitted December 16, 1947.

distribution through instincts of homing and gregariousness and through its individual demand for type and size of nesting territory. The size of the nesting population has much influence on the relative use of the different cover types.

The acreage-use ratio as a measure of cover adequacy is demonstrated unsound, chiefly because it overlooks many ecological aspects of the cover utilization problem, because it classifies covers on the basis of single plant dominants, and because it fails to consider marsh vegetation as dynamic. It is believed that classification and evaluation of covers as nest substrates must await a more thorough knowledge of the autecology of both birds and emergent plants. Marsh management must be premised on solid ecological understanding of natural processes.

Open water within the nesting covers is judged necessary to the pied-billed grebe, the coot, and the diving ducks. These are the local marsh-nesting birds which normally require open water for activities not directly related to the maintenance of a nest. Distance of nest from open water is demonstrated an unreliable criterion of open-water requirement. The most valid measure of open-water requirement is the correlation of nesting densities with amounts of open water and cover-water edge within the marshes. The many marshes within Dewey's Pasture were the main source of data in the investigation of this relationship.

The significance of both intra-specific and inter-specific tolerances to distribution of marsh-nesting bird populations is discussed. It is proposed that population saturation limits are often set by other influences than cover adequacy, and that tolerance or territorial behavior in marsh-nesting game birds be investigated with a view to reducing, if possible, the spatial requirements of individual nesting pairs.

Cover-water interspersions are described as the function of all the environmental factors, physical and biotic, operating in a marsh. As an environmental factor itself it is, under natural conditions, inextricably involved in the entire factor complex. For this reason, artificial creation of open water interspersions, as by blasting, creates an unnatural condition, for factors such as cover type and water depth, which are impingements on naturally occurring interspersions, are by-passed. Because of this, avian responses to artificial interspersions cannot be adduced from avian responses to interspersions resulting from natural processes. It is therefore recommended that interspersions, when lacking, be made available by manipulation of the more basic factors of water level and muskrat activity. Only when such manipulation is not feasible is blasting recommended as a technique for creating cover-water interspersions.

The blasting technique itself was investigated. From the experimental dynamiting done in 1939, 1940, and 1941 recommendations for its use were drawn up. It is suggested that unless lack of interspersions is the only limiting factor in cover utilization, blasting as an improvement will be abortive. When indicated, blasting should be done where a hard substrate, preferably sand and coarse gravel, occurs within three feet of the surface. The charge of dynamite should be sufficient to penetrate the

hardpan. Blasting should be done when the water table is at the surface or within four inches of it. Inundation of the excavation during the early period of stabilization appears preferable to exposure to air. The higher the elevation within the marsh basin the greater depth of excavation will be necessary to preclude emergent plant growth in the area it is desired to keep clear. Ditching dynamite of 50 per cent strength is recommended where the propagation method of blasting is employed. For post-hole shots, 60 per cent Extra dynamite is recommended. The best charging method for straight ditches is four sticks of dynamite every two feet in two parallel rows of charges four feet apart. A cross-shaped clearing is recommended for opening up the centers of kettle-holes and ponds of five to twenty acre size.

COLLAGEN AND ELASTIN CONTENT OF FOUR BEEF MUSCLES AGED VARYING PERIODS OF TIME¹

INEZ PRUDENT

From the Department of Foods and Nutrition, Iowa State College

This study was undertaken to test the widely-accepted hypothesis that the tenderization observed in beef during storage is due to a chemical degradation of collagen occurring post mortem, and to determine the elastin as well as the collagen content of the muscles selected. This was one phase of a project involving histological, physical, and organoleptic tests on beef of different grades.

Two animals were used for this part of the problem: one, a steer of "good" grade, which is the third down the list of United States standard grades, and the other, an eight-year-old dairy cow of "cutter" grade, which is next to the lowest. The carcasses were allowed to hang for twenty-four hours after dressing before the muscles were excised. In order to study muscles differing in tenderness, the psoas major or tenderloin, the longissimus dorsi or "eye" of the loin, the semitendinosus, and the biceps femoris were chosen. Each muscle was cut into three roasts, except the longissimus dorsi, which was cut into two portions before being divided into six roasts. The anterior portion was designated longissimus dorsi-ribs and the posterior portion, longissimus dorsi-loin. The roasts from each muscle were stored 1, 2, 5, 10, 20, or 30 days, according to a plan which made statistical analysis of the results possible. They were stored uncovered on enamel trays in the college cooler at 34°-36°F. for the allotted period and then carried to the foods laboratory, where samples were taken, the roasts were cooked, and the cooked samples were removed. The manner of cooking and sampling is described in the thesis of Dorothy Harrison, Iowa State College, 1947. The samples for chemical analysis were stored at -30°F. until analysis was made.

In addition to the collagen and elastin content of the muscle tissue, the total-nitrogen content and the dry weight were determined so that the final values might be independent of varying water and lipid content. Since the samples available were small, micro-methods were chosen. The dry weight was obtained by drying duplicate 2 to 7 gram samples of tissue in a constant temperature oven at 100°-116°C. to constant weight. The total-nitrogen content was obtained by determining the nitrogen content of the collection of centrifugates removed during the collagen and elastin extraction procedure, and combining this soluble-nitrogen value with the collagen- and elastin-nitrogen values.

For the determination of collagen and elastin a modification of the gravimetric method described by Lowry, Gilligan, and Katersky in the

¹ Doctoral thesis number 885, submitted December 17, 1947.

Journal of Biological Chemistry 139:795 (1941) was chosen. According to this method, triplicate samples of tissue weighing from 2 to 4 grams (A) were weighed into 50-milliliter round-bottom centrifuge tubes, mixed with weighed amounts of fine washed sand, and thoroughly macerated in mortars, then replaced in the centrifuge tubes. Two extractions of the soluble constituents were made with 40-milliliter portions of 0.1 N. sodium hydroxide, then a distilled water washing in which the pH was adjusted to 7. The phospholipids and lipids were removed by extracting with a 3:1 mixture of 95 per cent alcohol and anhydrous ether, and then with ether alone.

After each step in the extraction, the mixture was centrifuged and the supernatant liquid was poured off and retained, the ether centrifugate alone being discarded. The tube and residue were dried to constant weight (B) and then autoclaved with 20 milliliters of distilled water at 20 pounds pressure for 6 hours to convert the collagen to gelatin. This was centrifuged, and the supernatant liquid was retained and later combined with a 20-milliliter portion of wash water, these two portions comprising the collagen or gelatin fraction. The tube with the residue was again dried to constant weight (C), after which the residue was extracted with 0.1 N. sodium hydroxide for 30 minutes in a boiling water bath to remove intracellular proteins remaining, and then washed with 40 milliliters of distilled water. The centrifugates were added to the soluble-nitrogen accumulation. The residue (D) was dried to constant weight and calculations were made as follows:

$$\frac{B - C}{A} \times 100 = \text{percentage collagen}, \quad \frac{D}{A} \times 100 = \text{percentage elastin}.$$

Nitrogen determinations were made on the gelatin-containing centrifugate, on the elastin residue, and on the combined supernatant liquids by the usual micro-Kjeldahl procedure.

The results were calculated as collagen and elastin percentage as well as collagen- and elastin-nitrogen in per cent of total-nitrogen. The values differed greatly among themselves due to the difficulty of sampling but showed no relation to the duration of storage, either by inspection or by statistical analysis. There was a significant difference in collagen content between muscles, the psoas major having the least, the longissimus dorsi and the biceps femoris being intermediate, and the semitendinosus having the most. The collagen content of animal 1 expressed as collagen-nitrogen in per cent of total-nitrogen was as follows: psoas major, 1.53; longissimus dorsi-ribs, 2.59; longissimus dorsi-loin, 2.73; semitendinosus, 4.39; biceps femoris, 2.23. The cooked samples gave values in the same range, but slightly lower values in the longissimus dorsi and the semitendinosus. In animal 4 the figures for collagen on the same basis and in the same order were: 1.87, 4.69, 4.66, 5.90, and 4.60, much higher than in animal 1 in all cases except the psoas major, which was only slightly higher. Cooking decreased the collagen values of the psoas major and the longissimus dorsi-ribs of animal 4, but the values

for the other three were increased. This increase may be due to difficulties in sampling or to contamination of the gelatin centrifugate with other muscle proteins.

The elastin values of the four muscles of animal 1, expressed as elastin-nitrogen in per cent of total-nitrogen, were significantly different in the case of the semitendinosus only and were as follows: psoas major, 0.288; longissimus dorsi-ribs, 0.337; longissimus dorsi-loin, 0.512; semitendinosus, 4.39; and the biceps femoris, 0.531. For animal 4 the values on the same basis and in the same order were: 0.412, 0.311, 0.475, 1.65, and 0.475, which are lower, in general, than those for animal 1, especially in the semitendinosus. The elastin values of the cooked samples of both animals gave no evidence of an effect of cooking greater than the experimental error.

This study has shown that the collagen and elastin content of beef muscles are not affected by the duration of storage at 34°-36°F. for as long as thirty days. The explanation for the increase in tenderness of beef muscles during storage must be sought in physical rather than in chemical changes in the connective tissue.

The muscles of animal 4 (which was of inferior grade) had a higher collagen content but a slightly lower elastin content than those of animal 1.

There is a significant difference in the collagen content of different muscles correlated with their tenderness ratios and the force required to shear them. Cooking, however, exerts too small an effect on the collagen content to be significant at the 5 per cent level, and none that can be detected on the elastin content.

VIABILITY AND VIGOR OF INBRED AND HYBRID MAIZE SEED SUBJECTED TO FREEZING TEMPERATURES¹

ELMER C. ROSSMAN

From the Departments of Agronomy and Botany, Iowa State College

During the period 1921-45, there were eight years in which less than 90 per cent of the Iowa corn crop matured safely without frost damage. Premature killing frosts of 1945 resulted in considerable damage to the hybrid seed corn crop. The present investigation was undertaken to obtain information on the effects of several factors on freezing injury to seed corn.

Preliminary studies were conducted with air-dry shelled corn soaked at 45°F. to various moisture contents and given different freezing treatments. Viability of soaked seed was injured more than of seed with a similar moisture content in a freshly harvested condition. Seedling vigor of soaked seed was not reduced and there was no increase in percentage of weak seedlings as a result of freezing. All of the injured seeds were killed outright, suggesting that death may have resulted from intracellular ice formation. It was possible to obtain preliminary information on the relative tolerance of inbred lines by soaking and freezing air-dry shelled seed.

Ears with seed containing 65 to 30 per cent moisture were harvested from the field and frozen, with and without husks, under controlled laboratory conditions intended to simulate typical freezes as they might occur in the field. Temperatures of 26°F., 20°F., and 14°F. were used with exposures of 2, 4, 8, 16, or 24 hours.

Reduction of seed viability depended on the following factors: (a) temperature, (b) duration of exposure, (c) moisture content of the seed, (d) variety of seed, (e) rate of freezing, (f) rate of drying after freezing, (g) physiological maturity of the seed, (h) husk protection. In experiments involving the first four factors, significant interactions emphasized the difficulty of making accurate statements about the general effect of freezing conditions. It was necessary to consider all of the above factors in determining the injury that occurred. Loss of germination was directly related to moisture content of the seed and duration of exposure, and inversely related to temperature.

Rate of freezing influenced injury principally through an effect on the rate of cooling and duration of freezing. Ears that were precooled to 35°F. were more severely injured than ears warmed to room temperature before freezing. Less freezing damage may occur in the field after a warm day than after a cool day. Rate of thawing had no effect on the viability of frozen seed corn.

¹ Doctoral thesis number 889, submitted March 16, 1948.

Rapid drying after freezing was found to have a highly significant injurious effect. When frozen seed was allowed to dry slowly after freezing, germination averaged 20.3 per cent higher than corresponding seed dried in the seed-corn drier shortly after freezing. It may, therefore, be advisable to leave seed corn standing in the field for a time after freezing, since some recovery may occur with slow drying under field conditions.

Short, repeated freezing and thawing periods of 4 or 8 hours were less injurious than a continuous exposure of 24 hours. The first exposure was more injurious than subsequent exposures to the same freezing conditions.

Physiological maturity was measured by the percentage of the total dry matter accumulated. Seed at 30 per cent moisture was assumed to be physiologically mature and the dry weight of this seed was used in determining the percentage maturity at higher moisture contents. Some of the differences in freezing injury were explained on the basis of this measure of maturity. A higher maturity percentage appeared to be related to increased freezing tolerance when moisture contents were similar.

Inbred lines differed in tolerance of the seed to freezing temperatures. Husk protection was of more value to some inbreds than to others. Lines that were tolerant when frozen with husks on the ears were also tolerant when frozen without husks, indicating that some of the factors responsible for tolerance were associated with the seed itself. Tolerance was significantly correlated with seedling vigor and with physiological maturity of the inbreds; the more vigorous and rapidly maturing lines tended to be more tolerant. The relationship of tolerance to seed size was not significant.

The viability of some single-cross seed was reduced significantly more than inbred seed with the same maternal parent. In these cases, the hybrid seed tended to be physiologically more immature than the inbred seed at the same moisture content. Maternal characteristics of the seed were found to be relatively more important than embryo constitution. Where early frosts are a hazard in hybrid seed corn production, it appears that frost damage to seed viability may be reduced by using the more tolerant parent as the female parent, provided the two parents are of approximately the same maturity as measured by moisture content of the seed.

Freezing injury was greater in 1947 than in 1946, with the same varieties frozen at similar moisture contents. Hot dry weather during maturation of the seed in 1947 facilitated more rapid drying of the seed on the ear, so that, while the seed contained a similar moisture content when frozen in the two years, the 1947 seed was at a more immature stage of development and more susceptible to injury.

Germination of frozen seed was more rapid than of unfrozen seed, indicating that freezing temperature had an effect in breaking the dormancy of freshly harvested seed. When the seed had been dried to

approximately 9 per cent moisture, there was no difference in rate of seedling emergence.

Green weight of seedling tops from frozen, immature seed was generally reduced, and there was a larger percentage of weak seedlings than in unfrozen seed. Injury due to both intercellular and intracellular ice formation was postulated. There was no significant difference between the yield of corn grown from frozen and unfrozen seed when approximately equal stands were obtained.

TOXICITY OF AZOBENZENE AND CERTAIN RELATED COMPOUNDS TO INSECTS¹

SILAS S. SHARP

From the Department of Zoology and Entomology, Iowa State College

More than a century elapsed between the first preparation of azobenzene and the discovery of its insecticidal properties a decade ago, and only in the past two years has it achieved extensive use. This investigation was undertaken for the purpose of making a comparative study of the toxicity of azobenzene and certain related compounds and to investigate the method of action of azobenzene on insects.

Larvae of the housefly (*Musca domestica* Linn.) were used as the test insects in comparing the toxicity of twenty-four azo and related compounds. An effective method of mixing the chemical agents with the larval food medium is described.

As a result of screening tests, the following compounds were found to be nontoxic to housefly larvae at a concentration of two grams per 100 grams of food mixture: 2-amino-5-azoanisole, benzeneazoresorcinol, benzidine, Chrysoidin R, Congo red, *p*-dimethylaminoazobenzene hydrochloride, *p*-dimethylaminoazophenylarsonic acid, 4,4'-dinitroazoxybenzene, orange II, and Sudan III.

Azobenzene and nine other compounds were selected for detailed comparative testing. The data obtained were treated statistically and dosage-mortality lines computed. Inspection of the results revealed the order of toxicity of the compounds to be: phenylhydrazine, diazoaminobenzene, semicarbazide hydrochloride, phenylhydrazine hydrochloride, hydrazobenzene, azoxybenzene, azobenzene, hydrazine, *p*-aminoazobenzene, aminoazoxylene hydrochloride.

The American cockroach (*Periplaneta americana* Linn.) and housefly larvae were used in studying the toxic action of azobenzene. The poison was administered to fly larvae by mixing it with the rearing medium. Cockroaches were allowed to remain in contact with the powdered toxicant until death ensued.

Cockroaches with mouthparts sealed with cellulose acetate died when dusted with azobenzene, demonstrating that the material acts mainly as a contact poison by direct penetration of the integument. It was shown that any alimentary action is slight.

Fly larvae placed in contact with azobenzene-treated food assumed a lemon-yellow color; if exposed to lethal doses of the compound, they gradually became inactive and died in an extended position. Cockroaches maintained in contact with azobenzene became quiescent, usually falling

¹ Doctoral thesis number 863, submitted August 1, 1947.

over on their backs and succumbing to the poison in 24–40 hours. The nymphs were notably more resistant than the adults.

The yellow color of the metabolic decomposition products of azobenzene was of value in locating them in the insect body. Dissection of treated fly larvae revealed that the bright coloration was due to pigmented substances present primarily in the fat body and hemolymph, and to a lesser extent, in the alimentary canal and probably the Malpighian tubules. Internal examination of poisoned cockroaches disclosed that the yellow breakdown compounds were restricted to the hemolymph, parts of the alimentary canal, the fat body, the Malpighian tubules, and in the female imago, developing eggs.

Cockroach tissues were extracted with various solvents in order to remove decomposition products of azobenzene which might be present. The different methods of extraction are discussed.

During passage through the integument, azobenzene is changed to a water-soluble derivative which is carried by the hemolymph to the Malpighian tubules for slow excretion. Continued exposure to azobenzene results in the water-soluble derivative entering the hemolymph more rapidly than it can be excreted by the Malpighian tubules. When this level is reached the excess substance is absorbed by the fatty tissues of the insect and stored there pending excretion. Death apparently occurs when both the hemolymph and the fat cells have reached the saturation point for the toxicant or its metabolic decomposition products.

POTASSIUM FIXATION IN SOILS AS AFFECTED BY TYPE OF CLAY MINERAL, MOISTURE CONDITIONS, AND CONCENTRATION OF OTHER IONS¹

GEORGE STANFORD

From the Department of Agronomy, Iowa State College

Many soils fix large amounts of potassium in nonexchangeable form when dried following the addition of potassium. This fixation which occurs on drying has been studied quite extensively, and certain mechanisms have been advanced to account for the effect due to drying. The reversion of potassium to difficultly soluble forms under moist conditions has also been noted in certain soils, but the process by which this occurs has not been clarified. The present investigation is a study of the fixation of potassium under moist conditions and on drying in certain soils and in the clay minerals, montmorillonite and illite, known to occur in these soils. From these studies it was possible to determine that secondary micaceous minerals are responsible for the rapid fixation of potassium under moist conditions in certain calcareous soils. Moreover, it was shown that the fixation which proceeds slowly in acid soils under moist conditions upon addition of potassium is concerned also with this type of mineral.

Investigations of various factors which affect the amount of potassium fixed under moist conditions by illite have made it clear why fixation proceeds slowly, if at all, in acid soils and takes place rapidly in certain calcareous soils. In acid illite, iron and aluminum ions present in certain lattice positions greatly restrict entrance of K, and hence little or no fixation occurs under moist conditions. Precipitation of these aluminum ions as $\text{Al}(\text{OH})_3$ or as AlPO_4 , or the formation of a soluble complex with fluoride ions greatly increased the amounts of potassium fixed by electrodialyzed illite under moist conditions. That precipitation of AlPO_4 was of primary concern in bringing about the increase in fixation on addition of phosphate was shown by the fact that phosphate exerted an effect only in the pH range where precipitation occurs. The greater the amount of aluminum removed by complex formation with fluoride, the larger was the amount of potassium fixed.

When an acid-washed Webster soil, formerly calcareous, and no longer capable of fixing K under moist conditions, was treated with NaOH to raise the pH back to its former level, the capacity to fix potassium under these conditions was partially restored, although addition of phosphate or fluoride exerted no effect. This indicated that hydrogen ions as well as aluminum ions may inhibit potassium fixation in acid soils containing micaceous minerals. Rapid fixation of potassium in certain calcareous soils under moist conditions is explained by the fact

¹ Doctoral thesis number 883, submitted December 16, 1947.

that the micaceous minerals in these soils contain calcium, magnesium, and sodium ions in positions which are potentially capable of fixing potassium. Upon addition of potassium, these ions are easily replaced—much more readily than hydrogen, aluminum, or iron ions—and maximum fixation is attained within a 48-hour period.

Whether or not the addition of lime or phosphate fertilizer to a soil will bring about increased fixation of potassium is dependent to a considerable extent on the types of clay minerals present. Thus, while these amendments increase fixation in illite clay either under moist conditions or on drying, they decrease fixation of potassium by montmorillonitic clay. Failure to recognize the differential responses of these two minerals to the treatments noted has given rise to some confusion as to the effects on potassium fixation which are to be expected when soils are limed or phosphated. Results obtained in this investigation with clay minerals are directly applicable in reconciling certain conflicting results reported in the literature dealing with the influence of lime and/or phosphate on fixation of potassium in soils.

Addition of diethylamine-HCl to montmorillonite reduces almost to zero the capacity for fixation of potassium on drying; however, this reagent had little or no effect on the amount of potassium fixed by illite on drying. These results and other evidence obtained suggest that spatial limitations must be considered in interpreting the effects of large molecules or ions on fixation of potassium by these two types of minerals. Relatively large molecules or ions apparently have free access to the interplanar spaces of expanding lattice type minerals, but evidently do not penetrate the lattice structure of illite.

Illite fixes appreciable amounts of potassium under moist conditions when the pH is adjusted to near neutral or above. Considerably greater quantities are fixed when the mineral is dried. On the other hand, montmorillonite fixes no potassium under moist conditions, irrespective of pH, but fixes large quantities on drying, particularly at low pH values (4–5). Thus the fixation which occurs under moist conditions in soils is primarily due to minerals of the micaceous type, while that which takes place on drying is due to both major clay mineral types capable of fixing potassium, namely, montmorillonite and illite. Fixation of potassium under moist conditions in illite (pH 8.3) and in two calcareous Webster soils reaches maximum values at relatively low concentrations of added potassium. However, fixation on drying continues to increase as larger amounts of potassium are supplied. The possibility that fixation under moist conditions occurs in the more accessible positions at the edges of mica crystals is suggested as the chief reason for the limited capacity for fixation of hydrated potassium ions under these conditions.

The calcareous Webster soils which fix large quantities of potassium under moist conditions also are capable of fixing ammonium ions. These ions are fixed by the same mechanism. This was demonstrated in various ways. For example, it was shown that there was a correlation between the capacity for fixing potassium and ammonium in several soils. More-

over, if ammonium was fixed, the capacity for subsequently fixing potassium was correspondingly reduced. In a similar manner, fixation of potassium reduced the capacity for fixing ammonium by an amount approximately equivalent to the quantity of potassium previously fixed.

AN ECOLOGICAL STUDY OF THE MINNOWS OF THE DES MOINES RIVER, BOONE COUNTY, IOWA¹

WILLIAM CHARLES STARRETT

From the Department of Zoology and Entomology, Iowa State College

During 1946 and 1947 an ecological study was made of the minnows (Cyprinidae) of the Des Moines River and smaller streams in Boone County, Iowa. In the course of the investigation 721 collections in the Des Moines River and 100 collections from smaller streams were made with 10-, 20-, and 30-foot common sense minnow seines and with wire traps.

A total of fifty-three species are known to occur in Boone County. The southern channel catfish, *Ictalurus lacustris punctatus* (Rafinesque), and carp, *Cyprinus carpio* Linnaeus, are the only abundant food fishes in the river. The spotfin shiner, *Notropis spilopterus* (Cope), and southwestern sand shiner, *Notropis d. deliciosus* (Girard), are the most abundant species of minnows occurring in the Des Moines. The central big-mouth shiner, *Notropis d. dorsalis* (Agassiz), and the northern creek chub, *Semotilus a. atromaculatus* (Mitchill), are the most abundant species in the small streams. These minnows also occur in the Des Moines. The spotfin shiner is confined in the county to the Des Moines River drainage, and a species closely related to it, the redbfin, *Notropis l. lutrensis* (Baird and Girard), is limited to the Skunk River drainage system in the northeastern part of the county. The number of species of fish was found to increase with stream size. Several species of minnows were confined in their distribution to the Des Moines River.

Intolerance to other species is believed to be an important factor in the local abundance of the fathead minnow, *Pimephales p. promelas* (Rafinesque). The distribution of the western blacknose dace, *Rhinichthys atratulus meleagris* (Agassiz), is mainly limited to small bluff-creeks adjacent to the river where the stream gradient is greater. The hardness of a species to withstand low oxygen and limited space is considered an important factor in small streams subject to partial drying. In the river, habitat preference varied among some species with light intensity and season. The speckled dace remained in the channel regardless of light and season.

In this investigation 3,033 minnows, representing nineteen species, were examined for food habits and seasonal feeding trends. The spotfin shiner and some other species feed mainly during the daylight hours. The feeding habits of Des Moines River minnows can be classed into three main types. Some have a very specialized diet, others are partially specialized, whereas the southwestern sand shiner is quite omnivorous. The

¹ Doctoral thesis number 900, submitted June 3, 1948.

specialized feeders have little seasonal change in type of food. These specialized feeders are of two types: one feeding on bottom ooze and the other on dipterous larvae. The diets of the other minnows are modified by seasonal changes and availability of foods. Several species tend to select foods when a variety of foods is abundant.

Zooplankton is rather scarce in the Des Moines River. Entomostraca were almost entirely limited to late fall, winter, and early spring and appeared regularly in the winter collections when they composed 5 per cent of the plankton on the basis of count. These organisms are taken rather frequently in winter by most minnows. The scarcity of entomostraca in late spring and summer is believed to be a limiting factor to some fishes, including the yellow pikeperch, *Stizostedion v. vitreum* (Mitchill), western golden shiner, *Notemigonus crysoleucas auratus* (Rafinesque), and common emerald shiner, *Notropis a. atherinoides* (Rafinesque). Plankton, other than entomostraca, is of little direct importance to the minnows.

The bottom ooze in the Des Moines is an important food item for the brassy minnow, *Hybognathus hankinsoni* (Hubbs), bluntnose minnow, *Hyborhynchus notatus* (Rafinesque), central stoneroller, *Campostoma anomalum pullum* (Agassiz), and southwestern sand shiner. The latter species tends to use the bottom ooze as supplementary food when the availability of other foods is reduced. During high-water the bottom ooze is greatly reduced and this reduction may be of some importance in limiting the survival of the young bottom ooze feeding fishes.

Germinated seeds of *Salix* species are taken by all the minnows except the bottom ooze feeders in early summer. These young seedlings served to supplement the diminished food supply through the high-water periods in early summer of 1946 and 1947. Filamentous algae are only occasionally taken by most minnows. Seeds occurred regularly in the bullhead minnow and only occasionally in other minnows.

The small adult terrestrial insects were taken by minnows more in the fall than at other seasons. The increased feeding on terrestrial insects in the fall season seems to be associated with the abundance of these insects and with the reduction of Ephemeroptera nymphs and Trichoptera larvae.

Throughout the year aquatic nymphs and larvae form an important part of the diet of those Des Moines River minnows which are not strictly bottom ooze feeders. The Ephemeroptera nymphs and Trichoptera larvae comprise much of the summer diet. In winter and early spring dipterous larvae formed a large part of the diet of ten of the common minnows.

Severe interspecific competition for food was not thought to exist among the minnows during the course of this investigation. Although some competition possibly existed in the winter of 1946-47 for dipterous larvae, it appears that other compensating foods and diversified feeding habits of the minnows reduced the competition to a minimum.

The abundant species of minnows in the Des Moines River are late

spawners. Low-river stage in late summer probably favors the late spawning species.

Of the twenty-two species of minnows in the Des Moines River some are rare while others are the most abundant fishes in the river. This population is dynamic, and the responses to the environment depend upon the requirements of the individual species. Several consecutive years of low-river stages in the spring and early summer, followed by high-river stages later in the summer, could have a serious effect on the present abundant species and would tend to favor greater production of the early spawners. Based on a fifteen-year average of river stages, there seems to be little possibility of such a condition continuing over a long period, and the return of the river stages to the average would again favor the now abundant species. The total population of the minnows in the Des Moines River could remain somewhat constant with great changes in the relative abundance of its composite species.

PHOTOPERIODIC RESPONSES OF MAIZE¹

ROBERT O. THOMAS

From the Department of Botany, Iowa State College

Unusual growth responses often result from the introduction of maize from widely separated regions, especially when large changes of latitude are involved. Many of these are responses to a change in length of day, and may cause a serious problem for plant breeders attempting to utilize maize from different latitudes for hybridization.

When moved north to longer days during June at Ames, Iowa, many lines of corn collected in Guatemala and other Central and South American countries grow to abnormal heights and fail to tassel or shed pollen before the advent of shorter days in September and October. In contrast, adapted maize sheds pollen at Ames about August 1. When crosses between such extremes are desired, special treatments are required.

In the present study, field treatments of short-day induction were applied during the formative period to corn from various latitudes to determine the variation in and degree of response to different lengths of day. Field responses were obtained on an individual plant basis and included determinations of the presence or absence of floral primordia immediately following photoinduction, or of the time of subsequent flower response in tassel emergence, pollen shed, and silking, and of the number of nodes present at the end of the growing season. Chemical analyses of carbohydrate and nitrogen fractions of the plants were made from samples taken at the end of the induction period. Parallel experiments were run in the greenhouse during the winter months, utilizing the naturally short days of that season in comparison with a photoperiod extended by means of artificial illumination. One experiment was carried out to test the possibility of hastening flower response by application of synthetic growth substances.

Covering young corn plants in the field with light-proof boxes to shorten the day to eleven or twelve hours during June or July hastened the appearance of floral primordia in most Central American corns and accelerated the flowering of all lines tested, even of early Iowa corns. Marked differences in number of nodes were observed on Central American lines.

Shading the plants for four weeks, beginning four weeks after seedling emergence, was the most successful of the treatments applied. The gain in one Guatemalan corn was thirty-one days in time of first pollen shed. When given a four-week photoinduction period in Iowa, two of

¹ Doctoral thesis number 913, submitted June 7, 1948.

the Guatemalan corns shed pollen three or four weeks earlier than occurs normally at the high altitudes and lower temperatures of their native habitats in Guatemala. Table 1 shows this comparison.

The very considerable acceleration of flowering response in the

TABLE 1

NUMBER OF DAYS FROM EMERGENCE TO FIRST POLLEN SHED BY PLANTS FROM TWO COLLECTIONS OF GUATEMALAN MAIZE GROWN AT AMES AND IN GUATEMALA

Collection	Ames		Guatemala
	Photoinduction 11 hours	Natural day 13.5-16 hours	Natural day 11-13 hours
17A-46.....	78	109	100 *
33A-46.....	73	95	98 (7,500 feet) 106 (8,300 feet)

*Mean of three different plantings.

treated lines at Ames as compared with that in Guatemala is assigned to temperature differences. The mean monthly temperatures during the growing season at Ames were approximately 6°C. higher in July and 10°C. higher in August than the corresponding temperatures in Guatemala.

Of the plants under observation, the percentages showing specific flowering response before frost were increased by short-day photoinduction in each category of tasseling, shedding pollen, and silking. The greatest differences were in the latter more critical comparisons. These differences appear in Table 2.

In many cases silking appeared to be retarded. Since these plants were originally adapted in Guatemala to a growing season characterized by greater rainfall and lower temperature, it is reasonable to suspect that they were growing at Ames under a serious water deficit. With such conditions the tassel could outcompete the ear shoots for the available moisture and reach functional maturity at the expense of the latter.

Comparisons of carbohydrate and nitrogen fractions indicated no outstanding chemical differences which could be attributed to or associated with the effects of photoperiod on flowering. This lack of detectable chemical differences furnishes evidence that the photoperiodic response probably involves one or more specific reactions of the hormone type, and therefore cannot be reduced to terms of differences in macrochemical constituents.

Injections of 10 ml. of solution containing concentrations of 1, 10, and 100 p.p.m. of naphthaleneacetic or the sodium salt of 2,4-dichlorophenoxyacetic acids into young corn plants growing under long days did not hasten the formation of flower primordia.

Collections of maize from various latitudes representing wide differences in the day-lengths of the growing seasons of their original habitats have demonstrated marked differences in degree of response to

varying photoperiods when grown at Ames. Comparison with phenological data for certain of the Central American corns in their original habitats has indicated that a combination of relatively high temperatures with relatively short days furnishes optimum conditions for rapid dif-

TABLE 2

EFFECTS OF AN ELEVEN-HOUR DAY INDUCTION FOR FOUR WEEKS UPON SPECIFIC FLOWERING RESPONSES OF FOUR LINES OF GUATEMALAN MAIZE GROWN AT AMES, IOWA, IN 1947. DATA IN PERCENTAGES OF PLANTS

Line	Treatment	Tasseling	Shedding pollen	Silking
17A.....	induction 11-hour	100	96	48
	normal 13.5-16 hours	4	2	2
33A.....	induction 11-hour	92	72	76
	normal 13.5-16 hours	22	12	6
39A.....	induction 11-hour	100	64	68
	normal 13.5-16 hours	26	12	0
40A.....	induction 11-hour	84	72	60
	normal 13.5-16 hours	32	16	4

ferentiation and growth of reproductive structures in the material studied. The hypothesis that photoperiodism is conditioned by hormonal mechanisms is borne out by the lack of detectable chemical differences associated with photoperiodically induced flowering responses.

INHERITANCE AND INTERRELATION OF SOME AGRONOMIC AND CHEMICAL CHARACTERS IN AN INTERSPECIFIC CROSS IN SOYBEANS, *GLYCINE MAX* \times *G. USSURIENSIS*¹

CHARLES ROBERT WEBER

From the Department of Agronomy, Iowa State College

An interspecific cross in soybeans was made to obtain additional information relative to the segregation, mode of inheritance, manner of gene action, components of genetic and environmental variances, heritability, and the interrelations existing among five commercially important characters; namely, seed size, maturity date, protein percentage, oil percentage, and iodine number of the oil.

The wild soybean used, *Glycine ussuriensis*, had a procumbent habit of growth with long twining stems, small trifoliate leaves, slightly ellipsoidal, small, hard, sooty, black seed, early maturity, high protein percentage, low oil percentage, and high iodine number of oil. The cultivated soybean used, *G. max*, possessed characters in contrast to those of the wild species. The extent of differences between the two species in respect to the characters studied were as follows: *G. max* was ten times larger in seed size, matured 11 days later, was 9.5 per cent lower in protein percentage, 13 per cent higher in oil percentage, and was twenty-five points lower in iodine number of oil than *G. ussuriensis*.

G. max, variety Dunfield, was hybridized with *G. ussuriensis*, strain P. I. 65549, and grown in the same year with the parents, F_1 , and F_2 population. Seed size in grams per 100 seeds and maturity date were recorded on each of 1,628 F_2 's, the F_1 's, and each of the parent plants. The F_2 distribution was sampled for seed size at 0.1 gm. intervals. Approximately 10 per cent of the F_2 population was selected for evaluation of protein percentage, oil percentage, and iodine number of oil, and also for progeny testing in the F_3 generation.

In another year the parents, reciprocal F_1 's, selected F_3 lines, bulk F_2 and F_3 populations, and reciprocal backcross populations, were grown in a replicated design. All five characters were recorded on each generation and parents. The coefficients of variability for seed size and maturity date were relatively small, while those for each chemical character were unusually small. A high degree of accuracy in the measurement of each character was indicated by the relatively small experimental errors. Reciprocal F_1 hybrids were not shown to be different in any of the characters studied, indicating a lack of maternal inheritance.

Positive skewness of the F_2 and F_3 distributions for seed size was obtained. The largest seeded F_2 segregate was approximately one-half the size of the larger parent. The distribution possibly indicated that partially dominant factors determined small seed size, although geometric gene action was shown for this character. Seed size was correlated with

¹ Doctoral thesis number 910, submitted June 7, 1948.

the following characters: moderately negative with protein percentage, highly positive with oil percentage, and highly negative with iodine number of oil. The character was calculated to be 55 per cent heritable and conditioned by a large number of major and minor modifying genes.

Transgressive segregation for maturity date far beyond either parent was observed in the F_2 and F_3 distributions. The maturity date distributions indicated a lack of dominance of genes for this character. Maturity date was not associated with any of the characters studied. The nature of the gene interaction appeared to be additive for this character. Maturity date gave the highest heritability of 86 per cent, with the smallest number of genes.

Transgressive segregation for high protein percentage was observed in the F_2 and F_3 distributions. A partial dominance of genes determining high protein content was exhibited in all generations. Protein content appeared to be highly negatively associated with oil content and only moderately negatively associated with seed size. The nature of the gene interaction for protein content was additive or a combination of additive and multiplicative effects. Protein percentage was shown to be 70 per cent heritable.

The segregation for oil percentage indicated a relatively complex type of inheritance. Oil content did not exhibit dominance in any generation. Oil percentage was correlated with the following characters: highly positive with seed size, and highly negative with both protein percentage and iodine number of oil. Gene interaction affecting this character was largely of the additive type. Heritability of oil percentage was 64 per cent and it was conditioned by a relatively large number of genes. The data indicated that the oil percentage of the F_1 could be estimated by knowing the oil percentage of the parents.

Inheritance of iodine number of oil was similar to that of oil content. There was relatively little association of protein percentage with iodine number. Iodine number of oil was highly negatively associated both with seed size and oil content. Iodine number gave the lowest heritability, 47 per cent, of the characters studied.

Although the inheritance of the characters herein were those of an interspecific cross, it was postulated that the basic reaction of the polygenes involved in the expression of a character would give a similar reaction in a practical soybean breeding program involving crosses of cultivated varieties. The magnitude of expression of the character would depend, of course, upon the diversity of the alleles of the parents.

FAT METABOLISM IN YEAST¹

ALAN G. C. WHITE

From the Department of Bacteriology, Iowa State College

The synthesis of fat from acetate by *Saccharomyces cerevisiae*, according to the procedure first described by Smedley-MacLean and Hoffert (1923), has been confirmed. Consistent increases of about 110 per cent in the fat content of the metabolizing yeast have been obtained. The increases have been brought about by suspending 24-hour yeast cells in 25 volumes of a medium composed of 0.025 M or 0.25 M phosphate buffer with acetate as the sole source of carbon. A nitrogen source is absent; hence, little or no growth of the yeast is obtained. The resting cells, however, will carry out many normal metabolic processes.

Vigorous aeration of the medium was carried out by passing CO₂-free air through one-inch alundum balls placed at the bottom of the flasks in which the organisms were suspended. The air was bubbled through the suspension of cells at a rate of approximately one-half volume per minute.

Optimum conditions for the synthesis of fat have been found to be a pH between 6.5 and 7.5, an acetate concentration not greater than 0.1 M, cells approximately 24 hours old, and an aeration time of not over 48 hours. All experiments were conducted at 30°C. The effect of temperature has not been studied.

Dried or lyophilized cells which are often used for enzymatic studies do not synthesize fat to the same extent as fresh cells under the conditions given above.

The fresh yeast has been shown manometrically to slowly oxidize acetate and gives an R. Q. of 1.0, which indicates a complete oxidation of the substrate to CO₂ and H₂O. It was calculated that about one-half of the acetate would be utilized by 12 gm. wet weight of yeast cells in a 24-hour period. Determinations of the residual acetic acid indicate that even after 48 hours traces of the acid are present. The acid was qualitatively and quantitatively identified, according to the procedure of Osburn, *et al.* (1936).

It has also been shown by determination of the carbohydrate before and after aeration in the presence and absence of acetate that the added compound has a sparing action on the cellular carbohydrate. Less carbohydrate was utilized during the same aeration period by cells suspended in the acetate solution.

The fat, and fatty acids derived from the fat, synthesized during a 48-hour "resting" cell period have been shown to contain part of the C¹³ present originally in the carboxyl group of sodium acetate prepared

¹ Doctoral thesis number 874, submitted November 20, 1947.

by the Grignard procedure and neutralized to pH 7.2 with NaOH. The isotope, which was originally present in a concentration of 4.33 per cent excess in the carboxyl carbon, was present in the fatty acids in such concentration as to warrant the conclusion that the entire increase in fatty acid was synthesized from the added acetate. C^{13} from the acetate was also found in positions 3 and 4 of the glucose derived from the yeast carbohydrate. A similar situation obtains in animal tissue (Wood, *et al.*, 1945).

An indirect proof of utilization of the intact 2-carbon chain of acetate for fatty acid synthesis has been given. Duplicate experiments were set up, one of which contained labeled acetate plus normal $NaHCO_3$, the other normal acetate plus labeled $NaHC^{13}O_3$. On fractionation and isotope analysis of the constituent parts of the yeast it was found that the fat and fatty acids of the $NaHC^{13}O_3$ experiment did not contain the isotope. The carbohydrate fractions of both contained C^{13} in identical positions in the glucose molecule. This experiment indicates that $C^{13}O_2$ from the labeled bicarbonate did not exchange with the acetate molecule during fatty acid synthesis. Since acetate had previously been shown to be oxidized only to CO_2 and water, the intact 2-carbon unit must have been used as a unit for synthesis. As further proof that exchange did not occur through CO_2 , the residual acetate, isolated from the experiment with labeled $NaHC^{13}O_3$, contained no excess of C^{13} .

The role of acetaldehyde and acetyl phosphate as the 2-carbon intermediate in fatty acid synthesis has been examined. It was found that while sodium bisulfite is able to bring about a decrease in fatty acid synthesis, dimedon, another keto-fixative, is not. It has been suggested that this effect is due to impermeability of the cell wall to dimedon. By the use of sodium bisulfite as a fixative in microrespirometer experiments, an increase in acetaldehyde was observed. When calculated on a basis equivalent to the wet weight of yeast used in the large scale experiments, the acetaldehyde formed is sufficient to explain the increase in fatty acids.

Acetyl phosphate has not been found as an intermediate during the oxidation of acetate. The two methods of Lipmann and Tuttle (1944-45) have been used for its detection. Both gave negative values. It has been proposed, therefore, that acetaldehyde is the most likely 2-carbon compound for fatty acid synthesis from both acetate and carbohydrates.

A mechanism for fatty acid synthesis based upon an earlier scheme of Raper (1907) has been outlined. This outline has been proposed as the most plausible explanation of the known facts concerning fatty acid synthesis.

Several suggestions for future work on the problem have been given.

LITERATURE CITED

LIPMANN, F. AND L. C. TUTTLE

1944. Acetyl phosphate: Chemistry, determination and synthesis. *Jour. Biol. Chem.* 153:571-82.

AND

1945. A specific micromethod for the determination of acyl phosphates. *Jour. Biol. Chem.* 159:21-28.

OSBURN, O. L., H. G. WOOD, AND C. H. WERKMAN

1936. Determination of volatile fatty acids by the partition method. *Ind. Eng. Chem., Anal. Ed.* 8:270-75.

RAPER, H. S.

1907. Condensation of acetaldehyde and its relation to the biochemical synthesis of fatty acids. *Jour. Chem. Soc.* 91:1831-38.

SMEDLEY-MACLEAN, I. AND D. HOFFERT

1923. Carbohydrate and fat metabolism in yeast. *Biochem. Jour.* 17:730-41.

WOOD, H. G., N. LIFSON, AND V. LORBER

1945. The position of fixed carbon in glucose from rat liver glycogen. *Jour. Biol. Chem.* 159:475-89.

THE PREPARATION AND REACTIONS OF THE CHLOROMETHYL ETHER OF 2,3-BUTANEDIOL MONOACETATE¹

ERNEST L. WIMMER

From the Department of Chemistry, Iowa State College

Several microorganisms are known to produce 2,3-butanediol in good yield when grain mash is fermented. A major problem which has prevented this fermentation from becoming of industrial importance has been the difficulty in recovering the slightly volatile, water-soluble glycol from the large amount of dissolved solids and suspended material in the fermented beer. Senkus² added formaldehyde and an acid catalyst to the beer and distilled, at 78°–84°C., the azeotrope of 4,5-dimethyl-1,3-dioxolane and water and then recovered the 2,3-butanediol from the dioxolane by methanolysis. By this procedure 4,5-dimethyl-1,3-dioxolane is more readily available than 2,3-butanediol. The work here reported was undertaken to develop new derivatives of the dioxolane which could be obtained in good yield and might have value in the chemical industry because of their specific properties.

By reaction of acetyl chloride and 1,3-dioxolanes under proper conditions, Gresham³ obtained the highly reactive chloromethyl ethers of glycol monoacetates. The chloromethyl ether of 2,3-butanediol monoacetate (2-chloromethoxy-3-acetoxybutane) was prepared from 4,5-dimethyl-1,3-dioxolane in this study, and some of its many derivatives were prepared.

PREPARATION OF 2-CHLOROMETHOXY-3-ACETOXYBUTANE

meso-4,5-Dimethyl-1,3-dioxolane was prepared by a modification of Senkus' method in 87–90 per cent yield from *meso*-2,3-butanediol. This was cleaved by acetyl chloride to give 89 per cent of the theoretical yield of 2-chloromethoxy-3-acetoxybutane, b.p. 63.5°–64.5° (2 mm.), d_4^{25} 1.0975, n_D^{25} 1.4335. A catalyst was necessary and orthophosphoric acid was found satisfactory. Formaldehyde and hydrogen chloride were liberated when the compound was hydrolyzed in the cold.

2-Chloromethoxy-3-acetoxybutane was also prepared by the reaction in carbon tetrachloride of *erythro*-2,3-butanediol monoacetate, trioxymethylene, and anhydrous hydrogen chloride. Purification by distillation of the compound produced by this procedure was difficult. The *erythro*-2,3-butanediol monoacetate was prepared from *meso*-2,3-butanediol and acetic acid and its purification by distillation was also very difficult. The

¹ Doctoral thesis number 909, submitted June 7, 1948.

² Ind. Eng. Chem., 38:913–16 (1946).

³ U. S. Patent 2,377,878, June 12, 1945. Chem. Abst., 39:4097 (1945).

over-all yield of 2-chloromethoxy-3-acetoxybutane by this method was poor.

REACTIONS OF 2-CHLOROMETHOXY-3-ACETOXYBUTANE

A series of 4-acetoxy-3-methyl-2-oxapentyl esters ($\text{CH}_3\text{CH}(\text{OAc})\text{-CH}(\text{CH}_3)\text{OCH}_2\text{OOCR}$) was prepared by the reaction of 2-chloromethoxy-3-acetoxybutane and the sodium salts of carboxylic acids. Compounds prepared, physical properties, and yields were: acetate, b.p. $72^\circ\text{--}73.5^\circ$ (1.5 mm.), n_D^{25} 1.4200, 85.6 per cent; benzoate, b.p. $143^\circ\text{--}145.5^\circ$ (1 mm.), d_4^{25} 1.1135, n_D^{25} 1.4889, 79.8 per cent; adipate, b.p. $210^\circ\text{--}213^\circ$ (0.5 mm.), d_4^{25} 1.1094, n_D^{25} 1.4458, 76.2 per cent; stearate, m.p. $36^\circ\text{--}37^\circ$, 41.3 per cent (crude yield). The stearate was a colorless wax. The other compounds in the series were colorless, almost odorless oils. An attempt to produce the phthalate failed because the product could not be distilled above 200° without decomposition.

The reaction of carboxylic acid anhydrides and 2-chloromethoxy-3-acetoxybutane was a new type reaction. The products were the 4-acetoxy-3-methyl-2-oxapentyl ester and the acyl halide corresponding to the acid anhydride used. The reaction was effected by continuously distilling out the acyl halide as it was produced in the reaction. The reaction was only satisfactory when the acyl halide was the lowest distilling component. The esters prepared, physical properties not previously given, and yields were: acetate, 88.5 per cent; *n*-butyrate, b.p. $82^\circ\text{--}85^\circ$ (1 mm.), d_4^{25} 1.0268, n_D^{25} 1.4240, 81.3 per cent; benzoate, 52.7 per cent.

Cuprous cyanide and 2-chloromethoxy-3-acetoxybutane gave 82.3 per cent of 2-cyanomethoxy-3-acetoxybutane, b.p. $73^\circ\text{--}75^\circ$ (1 mm.), d_4^{25} 1.0368, n_D^{25} 1.4255. The nitrile was hydrolyzed with the calculated amount of water and excess sulfuric acid to 2-carboxymethoxy-3-acetoxybutane, which was not isolated. When the reaction mixture was treated with benzene and distilled, the benzene-acetic acid azeotrope was removed. The residual product was the lactone, 5,6-dimethyl-2-*p*-dioxanone, b.p. $54^\circ\text{--}56^\circ$ (4 mm.), d_4^{25} 1.1130, n_D^{25} 1.4438. The yield was 83.7 per cent. The colorless oil dissolved slowly in water with the formation of acid and was relatively stable toward spontaneous polymerization. The molecular weight after four months was 149 (monomer, 130). Treatment of 5,6-dimethyl-2-*p*-dioxanone with aqueous ammonia gave 89.5 per cent of 1-methyl-2-hydroxypropoxyacetamide, m.p. $63^\circ\text{--}64^\circ$.

When 2-chloromethoxy-3-acetoxybutane was treated with sodium alkoxides to prepare a series of mixed formals, the yields were poor because the acetoxy-group also was affected by the alkoxide. The sodium phenoxides reacted more smoothly. Sodium phenoxide yielded 50.0 per cent of 5-acetoxy-4-methyl-1,3-dioxahexylbenzene, b.p. $126^\circ\text{--}130^\circ$ (2.5 mm.), d_4^{25} 1.0652, n_D^{25} 1.4828; disodium resorcinat yielded 21.0 per cent of 1,3-bis(5-acetoxy-4-methyl-1,3-dioxahexyl)benzene, b.p. $183^\circ\text{--}188^\circ$ (1 mm.), d_4^{25} 1.0961, n_D^{25} 1.4710. Yields were low because the compounds polymerized in the still. These two compounds were also polymerized by mineral acids to brittle, red resins.

A successful method of preparing mixed formals was the condensation of 2-chloromethoxy-3-acetoxybutane and alcohols in the presence of pyridine. The reaction was carried out in chloroform solution which provided a homogeneous reaction medium. The chloromethyl ether was added dropwise to the solution of the alcohol in chloroform, and pyridine was added only as needed to neutralize the liberated hydrogen chloride, using methyl red as indicator. The expected 5-acetoxy-4-methyl-1,3-dioxahexyl-substituted hydrocarbons ($\text{CH}_3\text{CH}(\text{OAc})\text{CH}(\text{CH}_3)\text{OCH}_2\text{OR}$) were obtained. The alcohols used and the physical properties and yields of products derived were as follows: ethyl, b.p. $46^\circ\text{--}49^\circ$ (1 mm.), d_4^{25} 0.9737, n_D^{25} 1.4122, 65.0 per cent; isopropyl, b.p. $55^\circ\text{--}57.5^\circ$ (1 mm.), d_4^{25} 0.9599, n_D^{25} 1.4132, 75.0 per cent; allyl, b.p. $83.5^\circ\text{--}85^\circ$ (5 mm.), d_4^{25} 0.9836, n_D^{25} 1.4258, 86.0 per cent; *n*-butyl, b.p. $69^\circ\text{--}71^\circ$ (1 mm.), d_4^{25} 0.9520, n_D^{25} 1.4184, 78.4 per cent; cyclohexyl, b.p. $86^\circ\text{--}88^\circ$ (0.5 mm.), d_4^{25} 1.0007, n_D^{25} 1.4443, 66.8 per cent. Ethylene glycol gave 30.5 per cent of the mono-condensation product, 1-hydroxy-2-(5-acetoxy-4-methyl-1,3-dioxahexyl)ethane, b.p. $94^\circ\text{--}95^\circ$ (0.5 mm.), d_4^{25} 1.0706, n_D^{25} 1.4348, and 40.3 per cent of the di-condensation product 1,2-bis(5-acetoxy-4-methyl-1,3-dioxahexyl)ethane, b.p. $148^\circ\text{--}152^\circ$ (0.5 mm.), d_4^{25} 1.0657, n_D^{25} 1.4360.

Grignard reagents coupled with the chloromethyl ether, 2-chloromethoxy-3-acetoxybutane. *n*-Butylmagnesium bromide yielded 31.0 per cent of 2-*n*-amyloxy-3-acetoxybutane, b.p. $210^\circ\text{--}213^\circ$ (740 mm.), d_4^{25} 0.8971, n_D^{25} 1.4170. Phenylmagnesium bromide yielded 74.5 per cent of 2-benzyloxy-3-acetoxybutane, b.p. $94^\circ\text{--}96^\circ$ (0.5 mm.), d_4^{25} 1.0224, n_D^{25} 1.4858.

HOST-PARASITE RELATIONSHIP OF *CHALARA QUERCINA* AND SPECIES OF *QUERCUS*¹

ROY A. YOUNG

From the Department of Botany, Iowa State College

During the past five years oak wilt has become increasingly important in the upper Mississippi valley. Conservationists and foresters recognize wilt as the most serious problem in oak culture in Iowa. Little has been reported about the disease beyond the fact that it is caused by the fungus *Chalara quercina* Henry, and is most serious on trees of the red oak group. No method has been suggested that would account for the invasion and destruction of a fifty to sixty-foot red oak within a period of a few weeks. In order to learn more about the action of the pathogen, and to develop measures for alleviating its injury and reducing its spread, a series of field, greenhouse, and laboratory tests were made on the disease.

In the course of these investigations *Chalara quercina* was observed to overwinter commonly on white and bur oak trees, in stumps of diseased trees that had been removed, and occasionally, on red oak trees that were infected late in the season. Trees of the white oak group were shown to harbor the pathogen for several years. The fungus was isolated from all parts of diseased trees except the acorn. Mycelium and conidia were observed in xylem vessels of leaf midribs, petioles, and stems.

The manner in which hyphae or conidia are transferred from diseased to healthy plants is not known. The disease did not spread in a pattern typical of wind blown spore or insect dissemination. Oak wilt usually spread from an infection locus to the nearest healthy trees. Surveys of field plots showed the average infection distance to be about thirty to forty-five feet in dense to moderate stands. There was little difference in susceptibility of red and white oaks to infection. The percentage of infected plants in mixed stands was practically identical. Red oaks, however, were more rapidly destroyed than white oaks. No differences were observed in the incidence of infection of trees of different sizes.

Isolates from seven different species of oak showed no host specificity when inoculated into young oaks of twenty-eight species growing under greenhouse conditions. Isolates from each species produced typical disease symptoms when inoculated into other species. Some variation in cultural growth characteristics of the different isolates was observed.

Isolates of *C. quercina* grew well over a range from 16° to 28°C. with most rapid growth at 22°-26°C. The optimum temperature range

¹ Doctoral thesis number 911, submitted June 7, 1948.

for spore germination was 25°-30°C. At 25°C. endogenous conidia usually were produced from germ tubes of all germinating spores, while at 30°C. more than 85 per cent of the spores formed vegetative hyphae on germination.

The pathogen grew well on all complete nutrient media tested. Potato-dextrose agar and oatmeal agar supported the most rapid and abundant growth. The optimum growth on liquid medium occurred at pH 5 to pH 7 with limits at pH 3 and pH 9.

Spore germination was completely inhibited by 1 ppm. of malachite green, crystal violet, 8-hydroxy quinoline, copper 8-hydroxy quinoline, 8-hydroxy quinoline benzoate, 8-hydroxy quinoline sulfate, and phenylmercuri triethanol ammonium lactate. Even at 0.1 p.p.m. the 8-hydroxy quinoline derivatives were completely inhibitory to spore germination.

The action of crystal violet, as indicated by tests on mycelial disks, was probably fungistatic. Phenylmercuri triethanol ammonium lactate and 8-hydroxy quinoline sulfate showed the greatest fungicidal activity against *Chalara* mycelium. Fungus disks were killed by twenty-four-hour exposure to both 1000 and 100 p.p.m. of those compounds.

A metabolic product, which readily induced wilting of tomato and oak cuttings, was produced by *C. quercina*, when grown on a modified Richard's solution containing asparagine and yeast extract. Symptoms on toxin-wilted oak cuttings were typical of those produced on diseased greenhouse oaks.

Eradication experiments showed that the pathogen could be removed from an area by extreme sanitary measures. Incidence of infection was reduced by removal of diseased trees from areas of infection. However, the sanitary measures which provided satisfactory disease control were entirely too drastic to be of practical value for large-scale control efforts. Preliminary infection studies indicate that the pathogen is often restricted to the region of symptoms in white oaks. If so, pruning of mildly infected white oaks may offer a means of saving individual trees. Pruning of red oaks is of no value as a control measure due to the rapid dissemination of the organism throughout diseased trees.

These studies indicate that the fungus cannot establish itself in uninjured stem or leaf tissue. No successful inoculations were obtained without first providing a wound entrance for the pathogen. Once established in the host, however, the organism spreads rapidly throughout the tree. The abundant production of small conidia (2-3 x 4-7 μ) provides a means of rapid spread in the transpiration stream. Conidia are produced most abundantly at 20° to 28°C., a temperature range that prevails during the greater part of each summer day in this area. Conidial production begins almost immediately following spore germination and continues at a rapid rate as the fungus develops. Conidia were readily passed through sections of red and white oak twigs under suction.

The toxic substances produced in liquid culture are not specific for oak since they wilted tomato cuttings also. The symptoms produced by the toxic products are so similar to the ordinary symptoms associated

with oak wilt, that there can be little doubt that the toxic substances play an important role in disease production. Red, white, and bur oak cuttings, when placed in the culture filtrate, produced symptoms typical of greenhouse inoculated oaks. It is reasonable to assume, therefore, that the resistance in white oaks may be more appropriately attributed to restriction of invasion and growth of the fungus than to specificity of or immunity from the toxin.

NOTE ON AN INVARIANT OF COMMUTATIVE ALGEBRAS

B. VINOGRADO

From the Department of Mathematics, Iowa State College

Received March 18, 1948

In a paper on the structure of commutative algebras¹ G. Pickert studied a complete set of invariants for a wide class of associative commutative algebras with unit element, notably those with radical index less than four as well as those in which the radical has a single generator over the residue class field ("defect" equal to one). One of his invariants² (the rank of $[f_{ij}]$) carries with it the determination of a property we call cleavage; that is, the property of being the group direct sum of the radical and a semi-simple algebra over the ground field K . It is an adequate description in the case of commutative algebras to say that a non-nilpotent primary commutative algebra A is cleft if it is an algebra over a field (over K) isomorphic to the residue class field modulo the radical N .

It is the purpose of this note to prove that a certain wide class of commutative algebras³, which includes types to the cleavage of which Pickert makes explicit reference⁴, is uncleft. Restriction of A to primary algebras is of course unimportant and will be assumed hereafter.

1. As Pickert shows⁵, the ground field of A can be enlarged to a unique maximal separable subfield of A . Hence A/N will be assumed pure inseparable over K (K containing the maximal separable field), for only then can A possibly be uncleft.

Theorem: Let A/N be a pure inseparable field⁶ expressible as $K(C_1, \dots, C_n)$, where each residue class C_i is represented by an element c_i in A having $g_i^{r_i}$ as its minimum function, where $g_i = x^{p^{e_i}} - k_i$ is irreducible over K , k_i in K , $e_i > 0$, p the characteristic of K , and $r_i > 1$. Then A is uncleft if either (1) $g_i(c_i) \equiv 0 \pmod{N^{p^{e_i}}}$ for some i , or (2) the index of N is less than or equal to the greatest of the p^{e_i} .

Proof: Assume that A is cleft. Then $A/N^{p^{e_i}}$ is cleft. Represent the latter by $\bar{A} = K(\bar{c}_1, \dots, \bar{c}_n)$. If condition (1) holds then g_i^s , $s > 1$, is the minimum function of \bar{c}_i for at least one i . Write g and \bar{c} for brevity. The cleavage of \bar{A} and the lack of non-trivial automorphisms in A/N , imply.

¹Strukturtheorie der kommutative-associativen Algebren, Math. Ann. Vol. 116 (1938-39), pp. 217-80, hereafter referred to as Pickert.

²Pickert, p. 240.

³Perhaps the best known special case appears in Deuring, Algebren, Ergebnisse der Mathematik Vol. 4 (1935) p. 25.

⁴Pickert, p. 272.

⁵Pickert, p. 219.

⁶A canonical set of generators for pure inseparable adjunction is given by Pickert, p. 220, but is not used here.

the existence of an element \bar{n} in the radical of \bar{A} such that $\bar{d} = \bar{c} + \bar{n}$ has g as its minimum function, hence $g(\bar{d}) = g(\bar{c}) = 0$. This is a contradiction, so A is unleft. If condition (2) holds, then in A itself there must exist an n in N such that $d = c + n$ has g as its minimum function, where the subscripts have again been suppressed. This also is a contradiction.

If in the above theorem N is assumed to be generated by the c_i 's, subject of course to a consistent multiplication table, then condition (1) is a consequence of $r_i > 1$ for at least one i . The theorem could thus be stated in terms of a necessary and sufficient condition for such algebras.

2. Polynomial algebras are a noteworthy special case⁷ that comes within the scope of the theorem just proved. For them the cleavage property may be expressed in two ways:

A. An irreducible polynomial $g(x)$ is separable if, and only if, there exists a polynomial $h(x)$ such that $g(h[x])$ is divisible by $g^2(x)$.

B. If F is a field with characteristic $p \neq 0$, and if a quantity c has as its minimum function a power of an irreducible inseparable polynomial $g(x)$ with coefficients in F , then the polynomial algebra $F(c)$ is unleft. So any polynomial algebra is cleft if, and only if, every irreducible factor in the minimum function of its generator is separable.

For $F(c)$ there is the characterization that it is unleft if, and only if, there exists in $F(c)$ a non-nilpotent element d such that for no n in N does $d + n$ lie in a subfield of $F(c)$. Indeed, assuming $F(c)$ to be unleft, this element may be chosen from possible generators, say c . For if $c + n$ were in some field, then there would be an irreducible $h(x)$ such that $h(c + n) = 0$. But this gives $h(c) + n' = 0$ for n' in N , hence $h^q(c) = 0$. That is, c satisfies $h^q(x) = 0$. Hence $g(x) = h(x)$, which is a contradiction. So $c + n$ is in no field, no matter what n . On the other hand, if there exists a non-nilpotent d such that $d + n$ is in no field of $F(c)$, then the residue class \bar{d} will never have a representative in any field of $F(c)$. This is merely another way to say that $F(c)$ is unleft. In fact we may prove:

C. If a commutative algebra A (with unit) is a direct sum of simple extensions modulo N , then it is unleft if, and only if, there exists a non-nilpotent element d such that $d + n$ is in no subfield (over F) of A for any n in N . Let I be one of the two-sided ideals (primary) into which A decomposes. Then I is a field J modulo N . We need consider only the case where I is unleft. Then there exists d such that $F(d)$ contains a complete residue system for J . Clearly d must satisfy an inseparable irreducible congruence if I is to be unleft. If for some n in N (in fact, in the intersection of I and N), it were true that $d + n$ lay in a field, then this field would be a complete residue system, hence I cleft.

These results will naturally be compared with the so-called "Principle Theorem of Wedderburn," which states that an algebra is cleft if it is separable modulo its radical. For polynomial algebras this theorem states a necessary as well as sufficient condition.

⁷ Albert, Higher Modern Algebra, p. 247; Pickert, p. 274.

AQUATIC AND SHORE VEGETATION OF SPIRIT LAKE, DICKINSON COUNTY, IOWA¹

WILLIAM F. SIGLER²

*From the Entomology and Economic Zoology Section,
Iowa Agricultural Experiment Station*

Received April 2, 1948

A survey of the plants of Spirit Lake, carried on in conjunction with the study of the life history of the white bass (*Lepibema chrysops*), was made by the author in 1946. While the white bass of Spirit Lake apparently do not feed on plant material, the aquatic flora of the lake, nevertheless, has a direct effect on their ecology. The greatest concentrations of the smaller animals in the food chain—invertebrates, young-of-the-year, and other small fish—are either on or in the immediate vicinity of the submerged rooted aquatics. In the course of this survey, it was found that comparatively little data on the aquatic and marginal vegetation of Spirit Lake were available; for this reason, it seems desirable to place the results of the survey on record.

LOCATION AND DESCRIPTION OF SPIRIT LAKE

Spirit Lake, a rich eutrophic lake located in Spirit Lake Township in Dickinson County, includes all or part of sections 8, 9, 10, 11, 14, 15, 16, 17, 20, 21, 22, 23, 27, 28, and 29. The lake is an inverted L in shape with the horizontal arm extending east-west and the vertical arm north-south. The north-south axis is 4 miles long and the east-west axis slightly less than 3.5 miles long. The Spirit Lake watershed lies largely to the north of the lake in Jackson County, Minnesota. As indicated on a map of Spirit Lake published by the Iowa State Highway Commission (1917), the maximum depth of the lake recorded in 1916 was 27 feet. In 1946, no depth exceeding 23 feet was recorded when the lake was at the outlet level stage³ (U. S. Geological Survey gauge reading 14.2). The surface area of water exceeding 20 feet in depth is estimated at 26 per cent of the total 5,684 acres covered. The area between the 8-foot depth contour and shore is designated as the littoral zone, and is estimated to not exceed 5 per cent of the total acreage in the main body. Whereas the

¹ Journal Paper No. J-1529 of the Iowa Agricultural Experiment Station, Ames, Iowa, Project No. 764, and the Industrial Science Research Institute, Project No. 45, of Iowa State College; in cooperation with the Iowa State Conservation Commission and the U. S. Fish and Wildlife Service. Technical Paper No. 9 of Iowa Cooperative Fishery Research Unit.

² Now with the Department of Wildlife Management, Utah State Agricultural College, Logan, Utah, formerly of Iowa State College, Ames, Iowa.

³ All depths given in this paper are equivalent to the water level elevation at the outlet level stage.

north-south arm is at present shallower than was indicated by the Iowa Highway Commission map of 1917, the east bay is from 2-4 feet deeper than the readings given for 1916. During periods of high water, the outlet flows into East Okoboji Lake and on through the Okoboji Lake chain into the Little Sioux River. An outline map of the lake, including the 10- and 20-foot depth contours, is included here as Figure 1.

The terrain in the vicinity of Spirit Lake is remarkably varied for a prairie region. The area around the lake is frequently referred to as "Knobby Drift," which suggests a landscape of sharply defined hills

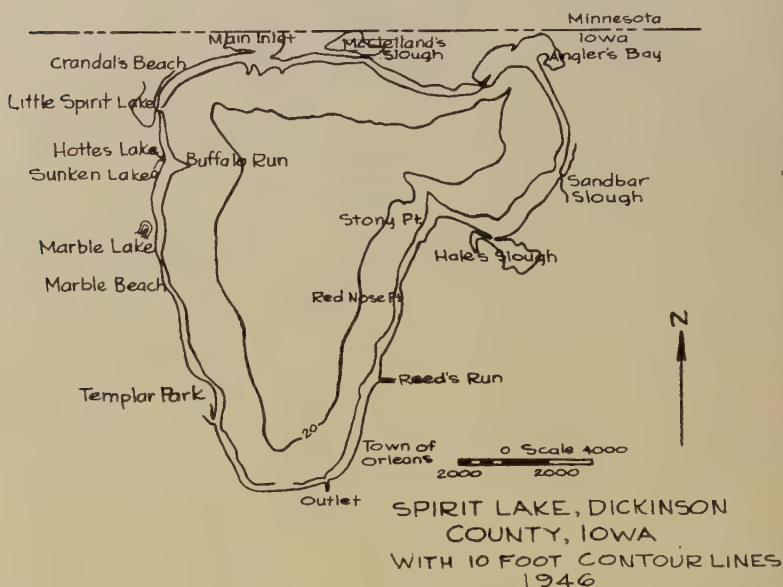


FIG. 1. Designation of 10-foot and 20-foot contours of Spirit Lake, Iowa.

either capped with sand and gravel or composed entirely of this material. These hills, known as kames, are features of the Wisconsin glaciation. Beneath the Wisconsin drift lies blue clay, and beneath that, sand and gravel. The entire thickness of the drift and Pleistocene sands and gravels probably varies greatly, but may be expected to be at least 250 feet thick in the vicinity of Spirit Lake. The lake lies in one of the great constructional depressions which, according to Macbride (1900), has no reference to any drainage system of recent times. The stream valleys of Dickinson County are peculiar and varied. As an example, the West Fork of the Little Sioux River is a torturous stream still eroding, while the East Fork lies in a wide valley, which might easily have formed the basin for a large lake. The geology of Dickinson County is discussed by Macbride (1900), Carman (1917), and others. The geology of adjacent

Jackson County, Minnesota, is treated by Upham (1884). Geologically speaking, Spirit Lake is, according to Macbride, relatively young.

VEGETATION OF THE SURROUNDING REGION

In a map published by the Iowa State Planning Board (1935), based on data secured in the original land survey 1832-1859, the original forest cover of northwest Iowa was confined almost entirely to stream basins. Macbride (1900) lists trees typical of an oak-hickory association as abundant locally along the east side of East Okoboji Lake and west and northwest side of Spirit Lake. The plants collected in 1946 from the north and east side of Spirit Lake were typically of the tall-grass prairie, while those plants from the northwest side are those often associated with oak-hickory forests. Macbride lists as common previous to 1900 several species of trees, including white ash, black walnut, and red oak, which were not collected by the present author in 1946.

Each species of aquatic plant has its own range of chemical conditions under which it thrives best, and within this range of tolerance the local distribution is greatly influenced by the type of bottom and the nature of the body of water. For example, Moyle (1945) states that in Minnesota most of the aquatic plants make their best growth on a mixture of sand and organic soil. In writing of the hard-water flora of Minnesota, Moyle states that this large and varied group of plants is typical of waters with a total alkalinity of 90 to 250 parts per million, with a sulphate ion concentration of less than 50 parts per million, and with a summer pH of 8.0 to 8.8.⁴ Moyle found a wide difference in tolerance for many species; some hard water species ranged into waters with concentrations of the sulphate ion as high as 300 parts per million. This concentration, however, seemed to be the upper limit of tolerance for nearly all hard-water species. The sulphate ion, according to Moyle, appeared to be more effective in limiting distribution than the concentration of carbonate salts. Hard water plants of the typical littoral zone of Minnesota are almost identical with those found in the littoral zone of Spirit Lake proper (see section on aquatic communities and annotated list).

While numerous plant collections have been made on West Okoboji Lake by the staff members and students of the University of Iowa, Lakeside Laboratory, and others; relatively few records are available for Spirit Lake. The algae of Dickinson County were studied by Tiffany (1926), Prescott (1931), and Smith (1926). Wylie (1920) reported the major vegetation of Lake Okoboji, and Shimek (1897 and 1915) reported on extensive collections made in Dickinson County.

With reference to adjacent counties, a comprehensive study of the plants of Clay and Palo Alto Counties was made by Hayden (1943). The flora of Emmet County was collected by Cratty over a period of forty years and reported in various articles. The *Flora of Emmet County* written

⁴ According to a test made April 10, 1947, total alkalinity of Spirit Lake was 267 parts per million, the sulphate ion concentration was 75.3 parts per million and the pH was 8.1.

by Wolden (1932) presents a list of 930 plants of which about 800 are native. Perhaps no county in the state has been so thoroughly surveyed from pioneer times to the present with reference to its native flora as Emmet County.

PLANT COMMUNITIES IN THE SPIRIT LAKE REGION

The main body of Spirit Lake is dominated by submergent plants, which represent an early stage in the hydrosere succession. Of these plants, during 1946, *Potamogeton richardsonii* was the dominant species. Another stage of succession, represented by the floating-leaved (partly submergent) plants, is found in the sloughs around and attached to Spirit Lake, and is represented by *Potamogeton natans* and *Polygonum natans*. The reedswamp is represented by the quite abundant *Scirpus acutus* in the lake proper, and by *Scirpus fluviatilis* in Hale's Slough, the water of which is uniformly $3\frac{1}{2}$ feet in depth.

Tansley (1939) uses the term marsh as applied to the "soil-vegetation type" in which the soil is waterlogged, the summer water level is at or near the surface, but normally not much above it, and the soil has an inorganic base. The normal summer water level of a swamp, according to Tansley's definition, is above the ground surface level. The swamp is usually dominated by reeds (*Phragmites*) or by other tall grasses, sedges, or rushes. A body of water of slight depth is considered by Hayden (1943) to be a pond. The areas described in this paper as sloughs fit this latter definition, except possibly during periods of high water, when they are generally considered as part of the main body of the lake.

The sedge-meadow stage described by Weaver and Clements (1929), in which *Carex* (sedge), *Juncus* (rush), and *Eleocharis* (spikerush) are the dominant genera, is typical of many sections of the east and north-east shore of Spirit Lake including Hale's Slough. *Elymus* (wild rye), *Beckmannia* (slough grass), *Leersia* (rice cutgrass), *Glyceria* (manna grass), and *Ranunculus* (crowfoot) growing north of Angler's Bay, just over the state line in Minnesota, are typical of the wet-meadow stage. The area between the highway and the lake front extending north from Marble Beach has plants, other than grasses, which are characteristic of prairie climax: *Solidago* (goldenrod), *Verbascum* (mullein), and *Aster* (aster); of the shrub stages, *Sambucus* (elderberry), *Ribes* (gooseberry), and *Rubus* (raspberry); and of the tree stage of the oak-hickory forest.

Data on the ecological communities may be conveniently divided into two sections: (1) shallow-water and adjacent dry land communities and (2) aquatic communities. These are discussed here in that order.

SHALLOW-WATER AND DRY LAND COMMUNITIES⁵

Marsh and wet-meadow, south end of Spirit Lake. Water 18 inches deep, clear. Area 1.5 acres. A forest derivative, area frequently modified by road building and park construction activities. June 4, 1946.

⁵ Dates given in the description of each community refer to the date when specimens were collected or plants listed.

SUBMERGENT

Chara sp.
Potamogeton zosteriformis
Utricularia macrorhiza

EMERGENT

Ranunculus sceleratus
Scirpus validus

Slough and prairie marsh area at east edge of Hale's Slough, Spirit Lake. Water 6 inches deep, 3 feet from shore. Silt bottom. A prairie area modified by man and domestic livestock. September 11, 1946.

SUBMERGENT

Ceratophyllum demersum
Najas guadalupensis
Polygonum natans
Zannichellia palustris

EMERGENT

Scirpus atrovirens
Scirpus validus

North of Marble Beach Public Access, oak-hickory association above rock beach. Stretch of shore line apparently changed only by the cutting of the larger species of trees valuable as lumber. September 18, 1946.

TREES

Carya cordiformis
Celtis occidentalis
Crataegus mollis
Fraxinus pennsylvanica
Populus tremuloides
Quercus macrocarpa
Robinia pseudoacacia
Tilia americana
Ulmus rubra

SHRUBS

Euonymus atropurpureus
Rhus glabra
Ribes cynosbati

Crandal's Beach area. Oak-hickory association back of sandy beach, September 14, 1946. The changes here represent those that generally accompany the building of homes.

TREES

Prunus virginiana
Quercus macrocarpa
Robinia pseudoacacia
Tilia americana

SHRUBS

Ribes cynosbati
Rosa blanda
Smilacina racemosa
Symphoricarpos occidentalis

FLOATING

Lemna minor
Lemna trisulca
Ricciocarpus natans

WET-MEADOW

Carex lasiocarpa
Carex vulpinoidea
Eleocharis calva
Scirpus pallidus

FLOATING

Lemna minor

WET-MEADOW

Bidens cernua
Cyperus strigosus
Echinochloa crusgalli
Eleocharis calva
Leersia oryzoides
Rorippa islandica
Scirpus validus
Sparganium eurycarpum

Sambucus canadensis
Symphoricarpos occidentalis

HERBS

Asclepias syriaca
Asparagus officinalis
Aster finkii
Aster paniculatus
Cirsium vulgare
Lactuca canadensis
Melilotus alba
Solidago altissima
Solidago gigantea
Verbascum thapsus
Verbena urticaefolia

HERBS

Amaranthus retroflexus
Carex blanda
Chenopodium standleyanum
Elymus virginicus
Eupatorium rugosum
Lactuca scariola
Leonurus cardiaca
Setaria lutescens
Urtica procera

Crandal's Beach. Area frequently covered by ice during winter. Occasionally swept by high waves. Sandy, sloping beach. Changes here, from the original condition, are few, except through the influences of cutting in the outlying timber. September 14, 1946.

TREES

Acer negundo
Fraxinus pennsylvanica

SHRUBS

Rhus glabra

HERBS

Ambrosia elatior
Artemisia campestris
Asclepias syriaca
Asparagus officinalis

Chenopodium album
Erigeron canadensis
Euphorbia esula
Euphorbia nutans
Lactuca scariola
Melilotus alba
Mirabilis nyctaginea
Physalis sp.
Polanisia graveolens
Polygonum hydropiper
Sporobolus cryptandrus
Taraxacum palustre
Verbascum thapsus
Xanthium italicum

AQUATIC COMMUNITIES

The location of each community is shown by number and the species present in each are indicated on the map in Figure 2. The species are listed in order of decreasing mass abundance. In many cases, *Potamogeton nodosus* may be associated with *P. illinoensis*.

(1) *Hale's Slough to Sandbar Area*

Gently sloping sand-mud to sand bottom. Outer extremity of *Scirpus acutus* 7½–8 feet deep. Heavy wave action. Moderate to high muskrat population intermittently. One beaver colony nearby.

(2) *Sandbar Slough to Angler's Bay*

Sand bottom grading to rock and sand, covered with organic material and silt.

(3) *Angler's Bay*

Flat, heavily covered (over sand) organic bottom. Water 2–4 feet deep. Protected from wave action, except on the west side which is affected by southwest winds. Very dense plant beds.

(4) *Trickel's Slough*

Flat, deep silt and organic material bottom. Water 3½–6 feet deep. Slight to moderate wave action. Supports large black bass population. Apparently quite attractive to migrating Anatidae. Quite shallow previous to 1943.

(5) *Northeast Shore*

Gently sloping sand-mud bottom. Shore somewhat rocky.

(6) *North Shore*

Sand Beach. Sand to mud bottom.

(7) *Inlet Bay*

Silt-organic bottom, water 6 feet deep. Previous to the 1943 rise of water, this bay was dominated by emergent plants. Slow current from Loon Lake, Minnesota, at times. One beaver colony in 1945, apparently abandoned in 1946.

(8) *Buffalo Run*

Rock-gravel shore. Rock bottom out 30-40 yards from shore.

(9) *West Shore*

Sand and rock shore. Sloping sand bottom grading to mud bottom.

(10) *South and Southeast Shore*

Sand shore. Gently sloping sand bottom grading into mud.

(11) *Big Stony Point-Little Stony Point and Red Nose Point*

Sand to rock-boulder bottom. Water shallow over the points; deep around them.

(12) *Jones' Pasture Area*

Rocky shore line. Rock to sand and silt bottom.

(13) *Hale's Slough*

A flat slough of approximately 65 acres, connected to Spirit Lake proper by a 30-foot channel. Water almost uniformly 3½ feet deep. Bottom deep mud and organic material. Muskrat population of moderate size, one beaver colony, carp and black bass spawning area, migrating waterfowl abundant.

ANNOTATED LIST OF PLANTS

The following list is based on plants collected by the writer, by the writer with Dr. Ada Hayden, and from previous Spirit Lake collections located in the Iowa State College herbarium. All plants listed here are at present in the Iowa State College herbarium. The collections by the writer and Dr. Hayden were made from June 1 to September 15, 1946. The shore and dry land collections were all taken within a radius of one-fourth mile of Spirit Lake. Plants are listed as occurring only where they were collected but in most cases their distribution is doubtless more widespread in the Spirit Lake region. The list of aquatic plants is believed to be much more complete than the list of terrestrial plants.

Identifications of plants were made by the use of various manuals, monographs, and floras. Names of plants used in this paper are those which are valid under the International Code of Botanical Nomenclature (1935).

In the determination and verification, assistance was received from Dr. Ada Hayden, Department of Botany, Iowa State College. Specimens of *Potamogeton illinoensis*, *P. natans*, *P. nodosus*, and *P. richardsonii* from the collection were verified by Dr. E. C. Ogden, Department of Botany,

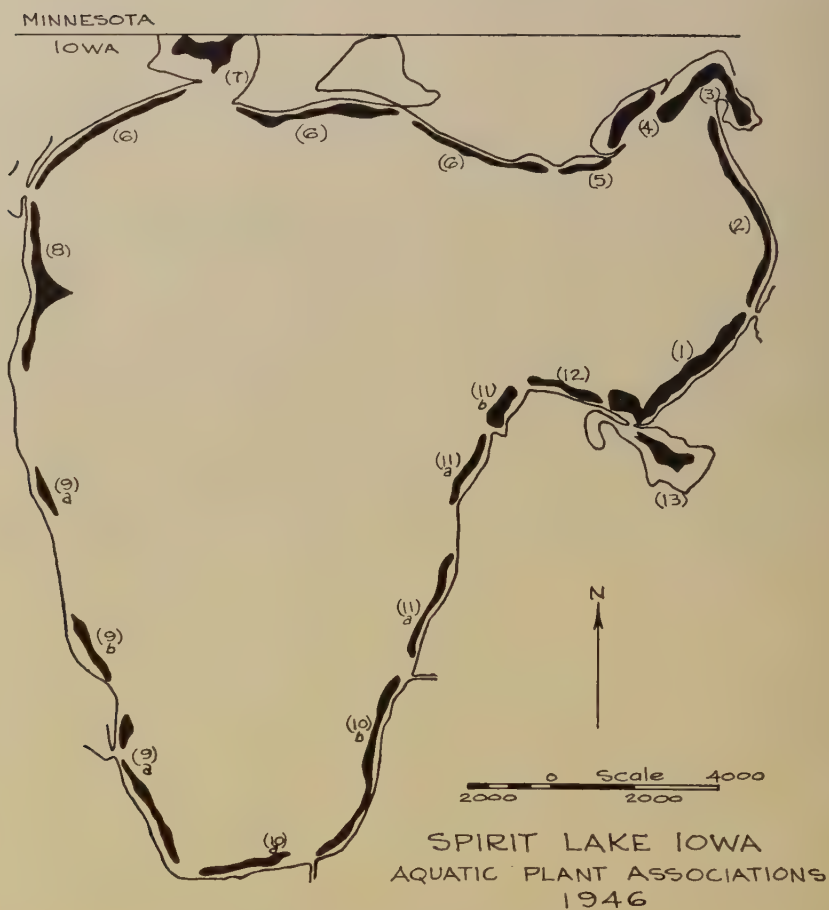


FIG. 2. Aquatic plant distribution in Spirit Lake.

FIG. 2. Aquatic plant distribution in Spirit Lake.

- (1)
Scirpus acutus
Potamogeton richardsonii
Potamogeton illinoensis
Potamogeton pectinatus
Myriophyllum spicatum
Potamogeton natans
Ceratophyllum demersum
Potamogeton zosteriformis
Typha latifolia
- (2)
Scirpus acutus
Potamogeton richardsonii
Potamogeton illinoensis
Potamogeton pectinatus
- (3)
Myriophyllum spicatum
Potamogeton pectinatus
Potamogeton zosteriformis
Potamogeton richardsonii
Ceratophyllum demersum
Potamogeton illinoensis
Najas flexilis
Scirpus acutus
- (4)
Myriophyllum spicatum
Potamogeton richardsonii
Ceratophyllum demersum
Potamogeton illinoensis
Potamogeton natans
Najas guadalupensis
Potamogeton zosteriformis
Ranunculus flabellaris
Polygonum natans
Potamogeton pectinatus
Scirpus acutus
Najas flexilis
Zannichellia palustris
- (5)
Scirpus acutus
Potamogeton richardsonii
- (6)
Potamogeton richardsonii
- (7)
Potamogeton pectinatus
- (8)
Scirpus acutus
Potamogeton richardsonii
Potamogeton pectinatus
- (9a)
Scirpus acutus
Potamogeton richardsonii
- (9b)
Scirpus acutus
Potamogeton richardsonii
Potamogeton pectinatus
- (10a)
Potamogeton richardsonii
- (10b)
Potamogeton richardsonii
Potamogeton pectinatus
- (11a)
Potamogeton richardsonii
- (11b)
Scirpus acutus
Potamogeton richardsonii
Potamogeton pectinatus
- (12)
Potamogeton richardsonii
Potamogeton pectinatus
Potamogeton illinoensis
Vallisneria spiralis
- (13)
Scirpus fluviatilis
Potamogeton natans
Ceratophyllum demersum
Polygonum natans
Lemna minor
Myriophyllum spicatum
Najas flexilis
Potamogeton illinoensis

University of Maine, Orono, Maine. Aid in the preparation of the manuscript was received from Dr. Duane Isely and Mr. Charles L. Gilly, both of the Department of Botany, Iowa State College.

Div. CHAROPHYTA
(Characeus plants)
CHARACEAE (Chara Family)

Chara contraria A. Br.

In extensive though not solid stands in water up to 15 feet in depth. More abundant on sandy bottoms. Complete range not known. (S&H 51).

Div. BRYOPHYTA
(Liverworts and Mosses)
Class HEPATICAE
(Liverworts)
RICCIACEAE (Water Liverwort Family)

Ricciocarpus natans (L.) Corda Purple-fringed Riccia
Common in pond at south end of Spirit Lake. Water 1.5 feet deep.
(Sigler 4).

Div. SPERMATOPHYTA
Subdiv. ANGIOSPERMAE
Class MONOCOTYLEDONEAE
TYPHACEAE (Cat-tail Family)

Typha latifolia L. Broad-leaved Cat-tail
Uncommon to common around Sandbar Slough. (S&H 19).

SPARGANIACEAE (Bur-reed Family)

Sparganium eurycarpum Engelm. Large Bur-reed
Abundant along the south and east side of Spirit Lake in marginal areas. (Sigler 61).

NAJADACEAE (Pondweed Family)

Najas flexilis (Willd.) Rostk. and Schmidt Slender Naiad
Rare, growing in water less than 1 foot deep, in Hale's Slough and Trickle's Slough (Sigler 31).

N. guadalupensis (Spreng.) Morong
Rare. Near shore in Trickle's Slough (Sigler 63).

Potamogeton amplifolius Tuckerm. Large-leaved Pondweed
(Cratty, 25,964) "A deep water form."

P. foliosus Raf. Leafy Pondweed
Uncommon in the outlet of Spirit Lake (which is subject to violent fluctuations and is frequently dry). (Sigler 150).

P. illinoensis Morong

P. lucens of American authors and
P. angustifolius of Cham. & Schlecht.

Common to rare in the main body of the lake, (S&H 5), uncommon in Angler's Bay, Hale's Slough, and Trickle's Slough. (Sigler 42). In water from 3-7½ feet deep; mud, or mud and rubble bottom. Often associated, and possibly hybridizing, with *P. nodosus*. Frequently it is near *P. richardsonii* on the deep-water side of the plant bed.

P. natans L.

Common Floating Pondweed

Abundant in Hale's Slough, (Sigler 50) (S&H 3), common in Trickle's Slough; uncommon between Sandbar and Hale's Slough, rare or absent elsewhere in the lake. In water from 3-5 feet deep; mud bottom. Usually absent in areas subject to intense wave action.

P. nodosus Poir.

P. americanus Cham. and Schlecht.
 See Rhodora 45: 123. 1943.

In Trickle's Slough and elsewhere with *P. illinoensis*. (S&H 50).

P. pusillus L.

P. panormitanus Bivona-Bernardi of Fernald.

Rare in east bay north of Hale's Slough. Growing in water from 2-4 feet deep. (S&H 6).

P. pectinatus L.

Sago Pondweed

Very abundant in the bay north of the footbridge and the second most abundant plant in Angler's Bay. Scattered sparsely in most areas where the water is not over 6 feet deep, but rarely in water less than 2 feet deep. Growing in mud and sand bottom. (Sigler 29).

P. praelongus Wulf.

Whitestem Pondweed

(Hitchcock 86,959).

P. richardsonii (Benn.) Rydb.

Clasping-leaved Pondweed

The most abundant and the most widespread plant in Spirit Lake. Growing in water from 2-7 feet deep; forming a band in open water and slough areas almost entirely around the lake; mud, mud and rubble, and mud and sand bottom. (Sigler 37) (S&H 2).

P. strictifolius Benn.

(Hitchcock 12,594).

P. zosteriformis Fern.

Eel-grass Pondweed

P. compressus of auths. not L.

P. zosterifolius of Amer. auth. not Schumacher.

See Mem. Gray Herb. 3: 36-40. 1932.

The third most abundant plant in Angler's Bay. (Sigler 49). Common

to rare in Trickel's Slough, growing in water from 1½–4 feet deep, in mud and sand bottom. (*Hitchcock 12,554*).

Zannichellia palustris L.

Horned Pondweed

Near shore in Trickel's Slough, growing in shallow water, rare. (*Sigler 67*).

ALISMACEAE (Water-plantain Family)

Alisma subcordatum Raf.

Water Plantain

Common along the eastern border of Spirit Lake. (*S&H 26*).

Lophotocarpus calycinus (Engelm.) J. G. Smith

Large Lophotocarpus

Very abundant locally at the southeast corner of Marble Lake. (*S&H 25*).

Sagittaria cuneata Sheldon

Arum-leaved Arrowhead

Abundant along east and northeast side of Spirit Lake. (*S&H 27*).

S. latifolia Willd.

Broad-leaved Arrowhead

Common in water one-half foot deep in Hale's Slough. (*Sigler 69*).

HYDROCHARITACEAE (Frog-bit Family)

Vallisneria spiralis L.

Freshwater Eel Grass

One bed just north of the east edge of Jones' pasture. (*S&H 1*).
Growing in open water 5–6½ feet deep, mud and sand bottom.

GRAMINEAE (Grass Family)

Alopecurus aequalis Sobol.

Short-awned Foxtail

Common along the northeast side of Spirit Lake near the shallow ponds. (*S&H 92*).

Beckmannia syzigachne (Steud.) Fern.

American Slough Grass

Uncommon north and east of Trickel's Slough. (*S&H 34*).

Echinochloa crusgalli (L.) Beauv.

Barnyard Grass

Common to abundant along the east edge of Hale's Slough. (*Sigler 56*).

Elymus virginicus L.

Virginia Wild-rye

Abundant in the timber of the northwest side of Spirit Lake. (*Sigler 110*).

Glyceria grandis S. Wats.

American Manna Grass

Uncommon along the northeast border of Spirit Lake. (*S&H 36*).

Leersia oryzoides (L.) Schwartz

Rice Cutgrass

Common along the Iowa-Minnesota line north of Angler's Bay. (*Sigler 55*).

Setaria lutescens (Weigel) F. T. Hubb. Yellow Foxtail
Common in the timber along the north and west side of Spirit Lake.
(Sigler 111).

Sporobolus cryptandrus (Torr.) Gray Sand Dropseed
Abundant in the sand along Crandal's Beach. (Sigler 99).

CYPERACEAE (Sedge Family)

Carex blanda Dewey Woodland Sedge
Uncommon along the edge of the timber near Crandal's Beach.
(Sigler 115).

C. lasiocarpa Ehrh., var. *latifolia* (Bockl.) Gilly
C. languinosa Michx.
In small pond at the south end of Spirit Lake. (Sigler 7).

C. sychnocephala Carey Long-beaked Sedge
Uncommon north of Sandbar Slough. (S&H 12).

C. vulpinoidea Michx. Fox Sedge
Common around the shallow ponds just south of Spirit Lake. (Sigler 5).

Cyperus strigosus L. Straw-colored Cyperus
Abundant on the sand beaches on the north side of Angler's Bay.
(Sigler 59).

Eleocharis acicularis (L.) R.&S. Needle Spike-rush
Common along the eastern border of Spirit Lake. (S&H 14).

E. calva Torr. Creeping Spike-rush
Common around the north and east border of Spirit Lake. (S&H 15).

E. macrostachya Britt.
E. smallii of Iowa authors.
E. palustris in part.
Rare north of Angler's Bay. (S&H 13).

Scirpus acutus Muhl. ex Bigelow Hard-stemmed Bulrush
S. occidentalis (Wats.) Chase.
Abundant in water from 5-7½ feet deep around the lake. (Sigler 33). Second in acres covered only to *Potamogeton richardsonii*; frequently associated with it. Growing on bottom ranging from rocks to deep mud. Attractive to muskrats.

S. atrovirens Willd. Dark-green Bulrush
Uncommon around the east side of Spirit Lake. (S&H 10).

S. fluviatilis (Torr.) Gray

River Bulrush

Abundant and dominant all over Hale's Slough. (Sigler 34). Growing in water $3\frac{1}{2}$ feet deep on mud bottom. Attractive to muskrats.

S. validus Vahl.

Soft-stemmed Bulrush

Abundant in very shallow water or marshy areas between Spirit Lake and East Okoboji. (Sigler 70).

LEMNACEAE (Duckweed Family)

Lemna minor L.

Lesser Duckweed

Abundant locally in Hale's Slough. (Sigler 54). Associated with *Ceratophyllum demersum*.

L. trisulca L.

Ivy-leaved Duckweed

Common in the shallow ponds south of Spirit Lake. (Sigler 11).

JUNCACEAE (Rush Family)

Juncus dudleyi Wiegand

Dudley's Rush

Uncommon along the Iowa-Minnesota line in marshy area. (S&H 22).

J. torreyi Coville

Torrey's Rush

Uncommon along the north shore of Angler's Bay. (S&H 23).

LILIACEAE (Lily Family)

Asparagus officinalis L.

Asparagus

Common along the edge of Crandal's Beach. (Sigler 87).

Smilacina racemosa (L.) Desf.

False Solomon's Seal

Abundant locally in the timber northwest of Crandal's Beach. (Sigler 101).

Class DICOTYLEDONEAE

SALICACEAE (Willow Family)

Populus tremuloides Michx.

American Aspen

Common along the rocky shores near Marble Beach. (Sigler 124).

JUGLANDACEAE (Walnut Family)

Carya cordiformis K. Koch

Bitternut Hickory

Common along the rocky beaches on the west side of Spirit Lake. (Sigler 130).

FAGACEAE (Oak Family)

Quercus borealis Michx.

Red Oak

Q. rubra of Gray, Man. ed. 7, and Britton and Brown ed. 2.

Reported by Macbride (1900) from northwest shore of Spirit Lake.

Q. macrocarpa Michx.

Burr Oak

Common to abundant along the west side of Spirit Lake. (Sigler 125). Often in association with bitternut hickory.

URTICACEAE (Nettle Family)

Celtis occidentalis L.

Hackberry

Common along the west shore of Spirit Lake. (Sigler 134).

Ulmus rubra

Red Elm

U. fulva Michx.

Uncommon to common along the west shore of Spirit Lake. (Sigler 149a).

Urtica procera Muhl. in Willd.

Slender Nettle

U. gracilis of most Amer. auth. not Ait.

See Rhodora 28:192-95. 1926.

Uncommon in the timber southwest of Crandal's Beach. (Sigler 106).

POLYGONACEAE (Buckwheat Family)

Polygonum aviculare L.

Dooryard Knotweed

Common north of Trickle's Slough. (S&H 32).

P. coccineum Muhl.

Pointed Water Smartweed

Persicaria muhlenbergii (Wats.) Small, in part.

P. muhlenbergii (Meisn.) Wats.

See Rhodora 24:162. 1925.

Common north of Sandbar Slough. (S&H 33).

P. hydropiper L.

Common Smartweed

Uncommon along Crandal's Beach above the average high-water line. (Sigler 82).

P. natans A. Eaton

Water Smartweed

P. natans A. Eaton

P. fluitans A. Eaton

See Rhodora 27:158. 1925.

Occasional in Hale's Slough and Trickle's Slough, rare to absent elsewhere. (Sigler 36). In water from 3½-5 feet deep, mud bottom.

P. ramosissimum Michx.

Bushy Knotweed

Not uncommon along the Iowa-Minnesota line north of Angler's Bay. (S&H 41).

Rumex maritimus L.

Golden Dock

Common around Angler's Bay in the marshy areas. (S&H 40).

CHENOPODIACEAE (Goosefoot Family)

- Chenopodium album* L. Lamb's Quarter
Abundant in the sandy soil along Crandal's Beach. (Sigler 93).
- C. gigantospermum* Aellen Maple-leaved Goosefoot
In the timber south of Crandal's Beach. (Sigler 122). Not common.
- C. standleyanum* Aellen
In sandy soil along the northwest shore of Spirit Lake. (Sigler 112).

AMARANTHACEAE (Amaranth Family)

- Amaranthus retroflexus* L. Upright Pigweed
Common along the border of the wooded areas, on the west side of the lake. (Sigler 107).

NYCTAGINACEAE (Four-o'clock Family)

- Mirabilis nyctaginea* (Michx.) Macm.
Oxybaphus nyctagineus (Michx.) Sweet Heartleaf Umbrella-wort
Common in the sand soil of Crandal's Beach. (Sigler 95).

CERATOPHYLLACEAE (Hornwort Family)

- Ceratophyllum demersum* L. Hornwort or Coontail
Common in Hale's Slough, Angler's Bay, and Trickel's Slough. (Sigler 43). Occasional in the edge of east bay. Rare or absent elsewhere. In water from 1½–5 feet deep. Growing on mud and sand bottom.

RANUNCULACEAE (Crowfoot Family)

- Ranunculus flabellaris* Raf. Yellow Water Crowfoot
R. delphinifolius Torr.
See Rhodora 38:171. 1936.
Uncommon in Trickel's Slough. (Sigler 40). Growing in 3½ feet of water on mud bottom.
- R. sceleratus* L. Cursed Crowfoot
Abundant in shallow ponds along the highway just south of Spirit Lake. (Sigler 3). Growing in one-half foot of water.

CRUCIFERAE (Mustard Family)

- Rorippa islandica* (Oeder ex. Murr.) Borbas Marsh Cress
R. palustris (L.) Bess.
Radicula palustris of Am. auth. not Moench.
Rorippa hispida (Desv.) Britt.
Radicula palustris var. *hispida* (Desv.) Rob.

See *Rhodora* 42: 26. 1940.

Abundant along the east edge of Hale's Slough in the marshy ground. (Sigler 60).

CAPPARIDACEAE (Caper Family)

Polanisia graveolens Raf. Small-flowered Clammy Weed
Abundant on Crandal's Beach. (Sigler 96).

SAXIFRAGACEAE (Saxifrage Family)

Ribes cynosbati (L.) Mill. Prickly Gooseberry
Common in the timber area north of Marble Beach Public Access. (Sigler 135).

ROSACEAE (Rose Family)

Crataegus mollis (T. & G.) Scheele Woolly Thorn
In the timber north of Marble Beach. Common. (Sigler 129).

Potentilla paradoxa Nutt. Bushy Cinquefoil
Along the Iowa-Minnesota line north of Angler's Bay. (S&H 45).
Common.

Prunus virginiana L. Choke Cherry
Common in the edge of the timber above Crandal's Beach. (Sigler 114).

Rosa blanda Ait. Smooth Rose
Abundant locally in the sand at the south end of Crandal's Beach. (Sigler 108).

Rubus occidentalis L. Black Raspberry
Growing on the rocky beach in the shade along the west side of Spirit Lake. (Sigler 149). Occasional.

LEGUMINOSAE (Bean Family)

Melilotus alba Desv. White Sweet Clover
Abundant along the beach at Crandal's both above and below the ice line. (Sigler 84).

Robinia pseudoacacia L. Black Locust
Growing sparsely south of Crandal's Beach. (Sigler 116). Possibly escaped from cultivation.

EUPHORBIACEAE (Spurge Family)

Euphorbia esula L. Leafy Spurge
E. virgata Wald. & Kit.
See *Rhodora* 39: 50. 1937.
Uncommon along Crandal's Beach. (Sigler 76).

- E. heterophylla* L. Various-leaved Spurge
 Uncommon in timber above Crandal's Beach. (Sigler 120).
- E. nutans* Lag. Upright Spotted Spurge
E. preslii Guss.
E. maculata of recent authors, but not of L.
 Common along Crandal's Beach. (Sigler 77).

ANACARDIACEAE (Cashew Family)

- Rhus glabra* L. Smooth Sumac
 Common in the edge of the timber south of Crandal's Beach. (Sigler 132).

CELASTRACEAE (Staff-tree Family)

- Euonymus atropurpureus* Jacq. Wahoo
 Common in the timber along the west side of Spirit Lake. (Sigler 131).

ACERACEAE (Maple Family)

- Acer negundo* L. Box Elder
 Abundant in the timber west of Spirit Lake. (Sigler 85).

TILIACEAE (Linden Family)

- Tilia americana* L. Basswood
 Commonly growing with the oak-hickory associations on the west side of Spirit Lake. (Sigler 133).

HALORAGACEAE (Water Milfoil Family)

- Myriophyllum spicatum* L. Water Milfoil
 The dominant plant in Angler's Bay, (Sigler 28), forming a heavy mat over much of eastern edge of the bay. Abundant in Trickel's Slough. Common in Hale's Slough. Uncommon to rare elsewhere. Growing in water from 1½-3½ feet deep, in mud, or mud and sand bottom. Never abundant in wind-swept areas.

UMBELLIFERAE (Parsnip Family)

- Sium suave* Walt. Hemlock Water Parsnip
S. cicutaeifolium J. F. Gmel.
 See Rhodora 17: 131. 1945.
 Along the road north of Angler's Bay. (S&H 43). Uncommon.

OLEACEAE (Olive Family)

- Fraxinus pennsylvanica* Marsh Green Ash
 North of Marble Beach. (Sigler 123). Common.

ASCLEPIADACEAE (Milkweed Family)

- Asclepias syriaca* L. Field Milkweed
In open areas along the west side of Spirit Lake. (Sigler 79).

VERBENACEAE (Verbena Family)

- Verbena urticaefolia* L. White Vervain
Along the lake shore north of Marble Beach. (Sigler 140). Uncommon.

LABIATAE (Mint Family)

- Leonurus cardiaca* L. Motherwort
West Shore of Spirit Lake in partially shaded areas. (Sigler 103). Uncommon.
- Lycopus americanus* Muhl. Cut-leaved Bugleweed
See Rhodora 38:374. 1936.
In low ground north of Angler's Bay. (S&H 46). Uncommon.
- L. asper* Greene Western Bugleweed
In low areas north of Angler's Bay. (S&H 47). Uncommon.

SOLANACEAE (Nightshade Family)

- Physalis* sp. Ground Cherry
Growing just out of reach of the waves along Crandal's Beach. (Sigler 94).

SCROPHULARIACEAE (Figwort Family)

- Verbascum thapsus* L. Great Mullein
Common in the open timber west of Spirit Lake. (Sigler 147).

LENTIBULARIACEAE (Bladderwort Family)

- Utricularia macrorhiza* LeConte Greater Bladderwort
U. vulgaris L. var. *americana* Gray
Abundant in the shallow ponds along the highway just south of Spirit Lake. (Sigler 1).

CAPRIFOLIACEAE (Honeysuckle Family)

- Sambucus canadensis* L. Elderberry
In the open areas of the timber north of Marble Beach. (Sigler 149b). Occasional.
- Symphoricarpos occidentalis* Hook. Western Buckbrush
Extremely abundant along the west and northwest shore of the lake. (Sigler 105). The dominant shrub. Growing under a wide variety of conditions.

CUCURBITACEAE (Gourd Family)

- Sicyos angulatus* L. One-seeded Bur Cucumber
Common on the sand around Crandal's Beach. (Sigler 119).

LOBELIACEAE (Lobelia Family)

- Lobelia siphilitica* L. Great Lobelia
North of Angler's Bay along the highway. (S&H 44). Uncommon.

COMPOSITAE (Sunflower Family)

- Ambrosia elatior* L. Common Ragweed
A. artemisiifolia L.
Abundant in unshaded areas all around the lake. (Sigler 83).
Artemisia campestris L. Sage
Along Crandal's Beach, often with lesser ragweed. (Sigler 78). Uncommon.
Aster finkii Rybd. var. *moratus* Shinnars
In the timber north of Marble Beach. (Sigler 143). Rare.
A. paniculatus Lam. Panicked Aster
North of Marble Beach, along shore. (Sigler 137).
Bidens cernua L. Nodding Bur Marigold
In shallow water, and along shore around Hale's Slough. (Sigler 65). Common.
B. frondosa L. Begger Ticks
Fairly common but not abundant around the lake. (S&H 48).
Cirsium vulgare (Savi) Airy-Shaw Bull Thistle
C. lanceolatum (L.) Hill
Common along the west side of Spirit Lake. (Sigler 148).
Erigeron canadensis L. Horse Weed
Growing above Crandal's Beach along the timber line. (Sigler 75). Not common.
Eupatorium rugosum Houtt. White Snakeroot
E. urticaefolium Reichard
See *Rhodora* 40:293. 1938.
Growing in the timber above Crandal's Beach. (Sigler 117). Occasional.
Lactuca canadensis L. Canada Lettuce
Rocky shore on the west side of Spirit Lake. (Sigler 145). Common.

- L. scariola* L. Prickly Lettuce
Timber area above Crandal's Beach. (Sigler 109). Common.
- Solidago altissima* L. Tall Goldenrod
Common around Spirit Lake. (Sigler 138).
- S. gigantea* Ait. Serrate-leaved Goldenrod
North of Marble Beach in the open timber. (Sigler 139).
- Taraxacum palustre* (Lyons) Lam. & DC. Dandelion
T. officinale Weber
See Rhodora 35:380. 1933.
Leontodon taraxacum L.
Common around the lake. (Sigler 81).
- Xanthium italicum* Mor. Common Cockle Burr
Common around Spirit Lake. (Sigler 80).

SUMMARY

The present report on a survey of aquatic and marginal plants of Spirit Lake, located in northwestern Iowa, includes 116 species representing 45 families. These are enumerated in an annotated check list in which pertinent facts concerning their distribution and ecology in the Spirit Lake region are recorded; significant synonymy is also given.

A brief physical and geological description of Spirit Lake and the surrounding region is presented. The vegetation of the surrounding region is discussed briefly.

A discussion of the plant communities existent in and about the lake is also presented. Five shallow-water and dry-land communities and thirteen aquatic communities are described, and the dominant and more abundant species in each are listed.

LITERATURE CITED

- CARMAN, J. ERNEST
1917. The Pleistocene Geology of Northwestern Iowa. Ann. Rpt. Iowa Geol. Survey. 26(1915):333-445.
- HAYDEN, ADA
1943. A Botanical Survey of the Iowa Lake Region of Clay and Palo Alto Counties. Iowa State Coll. Jour. Sci. 17:244-416.
- IOWA STATE HIGHWAY COMMISSION
1917. Iowa Lakes and Lake Beds. State of Iowa, Des Moines, Iowa.
- IOWA STATE PLANNING BOARD
1935. Restore the forest cover. 24 pp. (With map showing forest cover.) State of Iowa, Des Moines, Iowa.
- MACBRIDE, T. H.
1900. Geology of Osceola and Dickinson Counties. Ann. Rpt. Iowa Geol. Survey. 10(1899):185-239.

- MOYLE, JOHN B.
1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. *Amer. Midl. Nat.* 34:402-20.
- PRESCOTT, GERALD W.
1931. Iowa algae. *Univ. of Iowa Stud. in Nat. Hist.* 13(6):1-235.
- SHANTZ, H. L. AND RAPHAEL ZON
1924. Natural Vegetation. U.S.D.A. Atlas of American Agriculture. Part I, Sec. E.
- SHIMEK, B.
1897. Notes on aquatic plants from northern Iowa. *Proc. Iowa Acad. Sci.* 4:77-81.
-
1915. The geography of the Lake Okoboji region. *Bull. Lab. Nat. Hist., State Univ. of Iowa.* 7(2):3-69.
- SMITH, G. M.
1926. The plankton algae of the Okoboji region. *Trans. Amer. Mic. Soc.* 45:156-233.
- TANSLEY, A. G.
1939. The British Islands and their vegetation. 930 pp. London.
- TIFFANY, L. H.
1926. The filamentous algae of northwestern Iowa with special reference to the Oedogoniaceae. *Trans. Amer. Mic. Soc.* 45:69-132.
- UPHAM, WARREN
1884. The Geology of Cottonwood and Jackson Counties. *Geol. and Nat. Hist. Survey Minn.* 1:491-516.
- U. S. GEOLOGICAL SURVEY
1946. Unpublished prints showing water level elevations and yearly rainfall for Spirit Lake and Okoboji Lake from 1873 to September 1945. 2 pp.
- WEAVER, J. E.
1944. North American Prairie. *American Scholar.* 13:329-39.
-
- AND FREDERIC E. CLEMENTS
1929. *Plant Ecology*. 1st ed. 2nd imp. 520 pp. New York.
- WOLDEN, B. O.
1932. The plants of Emmet County, Iowa. *Proc. Iowa Acad. Sci.* 39:89-132.
- WYLIE, ROBERT B.
1920. The major vegetation of Lake Okoboji. *Proc. Iowa Acad. Sci.* 27:91-97.

SEED CHARACTERS OF COMMON CLOVERS (*TRIFOLIUM*)¹

DUANE ISELY

*From the Botany and Plant Pathology Section, Iowa Agricultural
Experiment Station*

Received April 19, 1948

Clovers occupy much of a seed analyst's time. Not only are the clovers among our most common and useful crops, but they are also sold in various grass and pasture seed mixtures. Such mixtures, which must be accurately analyzed, frequently contain the seeds of several kinds of clovers.

Seeds of ten species of clovers are illustrated by Hillman and Henry (1935), and the seed characters of alsike, white, red, and crimson clover are briefly described and illustrated by Musil (1942). There are, however, no complete descriptions of the seed characters of all species of clovers likely to be encountered by seed analysts in this country. This compilation has been devised, therefore, to provide complete descriptions, in one place, of all of the economically important species, whether crops or weeds. A few less common types are mentioned secondarily.

GLOSSARY OF DESCRIPTIVE TERMS

The taxonomic vocabulary for seeds is so incomplete that it is frequently difficult to describe them precisely without coining special terms or employing certain words in a restricted or special sense. Terms applied to clover seeds in this paper are defined as follows:

Accumbent—medianly recurved with the radicle lying against the cotyledon margins.

Basal (end or margin)—the end of the seed at which the embryo is bent; opposed to the terminal extremity (see Fig. 2).

Collar—a slightly raised flange or rim about the hilum.

Cotyledonary lobe—the segment or lobe of the seed containing the cotyledons (see Fig. 2).

Divergent—directed outwards; away from.

Ellipsoidal—(as contrasted with ovoid) widest at the middle and of the same width at both ends (see Fig. 1).

Elongate—longer in one axis than the other two.

Emarginate—notched or shallowly lobed.

Embryo—the undeveloped plant within the seed.

Flush—level with the adjacent surface; not terminating in a lobe or projection.

¹ Journal Paper No. J-1542 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project 86.

Furrow—an external depressed longitudinal line following adjoined cotyledon and radicle margins (see Fig. 2).

Hilar notch—the emargination in which the hilum is located (see Fig. 2).

Hilum—the attachment scar of a seed.

Included—not projecting; contained within the seed proper.

Lateral (margin)—one or the other of the elongated sides of the seed, one outlined by the longitudinal margin of the cotyledons, the other by the radicle (see Fig. 2).

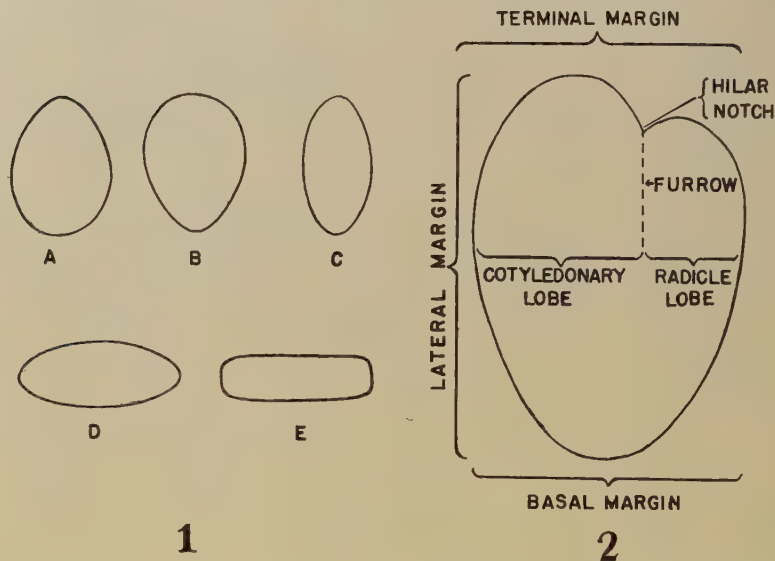


Fig. 1 (left). Diagrammatic representation of certain terms employed in text: A. Ovate (3-dimensional equivalent, *ovoid*). B. Obovate (3-dimensional equivalent, *obovoid*). C. Elliptical (3-dimensional equivalent, *ellipsoidal*). D. Plump seed cross-sectional shape. E. Compressed or flattened seed cross-sectional shape.

Fig. 2 (right). Red clover, diagrammatic.

Micropyle—an inconspicuous aperture or a small spot on the seed coat located on radicle side of hilum.

Ovoid—egg shaped, one end broader than the other (see Fig. 1).

Radicle lobe—the segment or lobe of the seed containing the radicle (see Fig. 2).

Reniform—kidney-bean shaped; in side view with one straight or convex, and one concave longitudinal margin.

Strophiole—a small area in proximity to hilum on cotyledonary side; usually contrasting in color or texture with the rest of the seed.

Terminal (end or margin)—the end of the seed outlined by the distal portion of the cotyledons and tip of the radicle; opposed to the basal extremity (see Fig. 1).

Truncate—blunt; neither rounded nor pointed.

Tubercular—possessing minute projections or prominences.

Umbonate—slightly raised or swollen.

GENERAL CHARACTERISTICS OF *TRIFOLIUM* SEEDS

The seeds of *Trifolium* herein considered are ovoid to ellipsoidal or oblong-ellipsoidal in general appearance. In cross-section they range from plump to somewhat compressed or flattened. The hilum is marginal in a conspicuous or inconspicuous notch. It, as well as the notch in which it occurs, may be terminally located, the resultant seed shape being nearly or approximately bilaterally symmetrical (as in *T. hybridum*), or it may have a lateral position, resulting in a seed of distinctly asymmetrical form (as in *T. pratense*). In size, the seeds range from approximately 1 mm. in length (as in *T. arvense* or *repens*) to 4 mm. (as in *T. subterraneum*).

The hilum lies just beyond or to one side of the terminus of the radicle lobe. It is usually circular in form, whitish, scurfy, or brownish in appearance. The strophiole and micropyle are both located in close proximity to the hilum. The micropyle, when discernible, appears as a minute black dot at the margin of the hilum on the radicle side. The strophiole, located on the opposite side of the hilum, may or may not be clearly evident. It commonly appears a slightly darkened area in which a short, longitudinally extended slit often is evident. In some species it is slightly raised as an umbonate, dark-pigmented prominence (as in *T. arvense*).

Clover seeds vary in color from yellow or greenish-yellow to dull black or purplish. Those of some species are mottled or blotched. Various colors may be observed in seeds of the same species, dependent upon the age or stage of maturity when harvested. Usually immature or shriveled seeds soon take on a dull brown coloration. Changes in color with increasing age are most distinct in species with light colored seeds; e.g., white clover, the hop clovers, or yellow seeds of red clover. Such seeds, after a year in storage, usually lose their bright yellowish appearance and become an orange-yellow. Later they may become dull orange and eventually reddish-brown or brick-red. The surface of the seed coat in most species is smooth and either shiny or dull in appearance. In contrast, seeds of *T. parviflorum* and *T. stoloniferum* are finely roughened or tubercular.

The seed of *Trifolium* consists of a thin endosperm layer and an embryonic plant inside the seed coat. The embryo is of an accumbent type with the radicle recurved and appressed against the margin of the cotyledons. In some species, the radicle is as long as the cotyledons, in others, shorter. This variation is the most important factor contributing to variation in the external form of the seeds. If the radicle is shorter than the cotyledons (as in *T. pratense*, Fig. 11), the seed shows a marginal notch or concavity on the radicle side where the radicle fails to extend to the end. If the radicle is nearly equal to the cotyledons (as in *T. hybri-*

dum, Fig. 8), the notch, if present, is terminal, and the seed appears much more nearly symmetrical. The longitudinal furrow visible on seeds of many species follows the line of juxtaposition of the cotyledons and the radicle.

While most of our cultivated species of *Trifolium* may be identified readily by their seed structure, it is unusual that varieties or strains of a particular species can be differentiated by their seeds.

DISTINCTIONS BETWEEN SEEDS OF *TRIFOLIUM* AND THOSE OF RELATED GENERA

Trifolium seeds are markedly similar in appearance to those of several other legumes, and no single characterization will completely differentiate them.

Agronomic species of *Medicago* and *Melilotus* may perhaps be most easily confused with certain species of *Trifolium*. Most *Medicago*² seeds present a laterally elongate or reniform appearance differing from the ovoid or obovoid form typical of the greater number of *Trifolium* species. Certain seeds of alfalfa (*Medicago sativa*) may closely resemble red clover. Distinction, in most cases, can be made on the basis of the more flattened, angular or twisted shape, and the less glossy color of the alfalfa. Black medic (*Medicago lupulina*) seeds are similar to the seeds of several species of *Trifolium* but may be distinguished by the presence of a well-marked, divergent projection contiguous to the lateral hilum (i.e., in black medic) and by their plump shape and dull yellowish-green color. Sweet clover (*Melilotus alba* and *M. officinalis*) seeds are sometimes confused with those of red clover. Sweet clover seeds are more flattened, less distinctly notched, and possess a more nearly terminal hilum than red clover; they thus present a more nearly symmetrical appearance. Sweet clover, furthermore, possessing a rougher and more granular seed coat, does not exhibit the shiny surface characteristic of well-developed seeds of red clover.

Instances have come to the writer's attention of crimson clover seeds being confused with those of *Sericea lespedeza* (*Lepedeza sericea*). The latter are smaller and more flattened than crimson clover, and the surface is inconspicuously mottled.

DESCRIPTIVE TREATMENT

It should be emphasized that synoptical keys, illustrations, and descriptions having reference to such objects as closely similar seeds are, at best, only "guide-posts." Such guides are no substitute for the subtle distinctions which can be made through the medium of close familiarity gained by continued experience. To "know" clover seeds, one must acquire this experience.

²The common forms of *Medicago* are discussed in detail in another paper (Isely, 1947).

SYNOPSIS OF PRINCIPAL DISTINCTIONS BETWEEN SEEDS OF
NINE COMMON SPECIES OF CLOVER

This synopsis will not provide infallible identification of the species treated—immature seeds are particularly troublesome in this respect. It presents a quick reference outline tabulation and should be employed in conjunction with the more complete descriptions which follow.

- A. Seeds 1.7–2.5 mm. in length; radicle lobe 0.4–0.8 as long as cotyledonary lobe; hilum lateral.
 - B. Seeds 2.2–2.5 mm. in length, ellipsoidal, nearly symmetrical; radicle lobe non-evident, nearly included; surface yellowish to orange-yellow.....Crimson clover (*T. incarnatum*)
- BB. Seeds 1.7–2 mm. long, strongly lobed or asymmetrical; radicle lobe evident, frequently somewhat divergent; surface yellowish to purple-black.....Red Clover (*T. pratense*)
- AA. Seeds up to 1.3 mm. in length; radicle lobe from (0.7) 0.8–1.1 as long as cotyledonary lobe; hilum terminal to obliquely lateral.
 - C. Seeds yellowish-green to greenish-black or black (immature shrunken ones may be dull red-orange), mostly 1.2–1.3 mm. in length.
 - D. Seeds shiny, “oily,” yellowish-green to greenish-black, radicle lobe equaling or slightly exceeding cotyledonary one.....Persian clover (*T. resupinatum*)
 - DD. Seeds not shiny, dull green to black; radicle lobe usually slightly shorter than cotyledonary one.....Alsike clover (*T. hybridum*)
- CC. Seeds yellowish to orange-yellow, sometimes faintly greenish marked, mostly 1–1.2 mm. in length.
 - E. Seeds dull or slightly glossy; hilum subterminal or terminal; usually in a distinct notch; furrow generally evident.
 - F. Seeds ellipsoid to obovoid, usually plump; apex rounded; hilum in a shallow subterminal concavity; upper portion of furrow frequently dark in color; surface of seed characteristically a pale lemon-yellow.....Rabbit’s-foot clover (*T. arvense*)
 - FF. Seeds obovoid, usually compressed; apex truncate, emarginate, or asymmetrically notched; hilum oblique or terminal; furrow not darkened; surface of seed dull yellow, orange-yellow, or with a faint greenish cast.
 - G. Hilum usually terminal, radicle lobe generally nearly equaling cotyledonary one; seeds characteristically 1.0–1.1 mm. in length, usually entirely yellowish.....White clover (*T. repens*)

- GG. Hilum usually oblique, radicle lobe generally slightly shorter than cotyledonary lobe; seeds characteristically 1.1–1.2 mm. in length, usually faintly greenish towards base.....
Hop clover (*T. agrarium*)
- EE. Seeds shiny or glossy; hilum lateral to subterminal, nearly flush with the margin, or if in a distinct notch, usually lateral in position; furrow usually indistinct or absent.
- H. Seeds broadly ellipsoidal, about 0.8 mm. wide, weakly notched.....
Suckling clover (*T. dubium*)
- HH. Seeds more narrowly ellipsoidal than above, about 0.6 mm. wide, distinctly notched.....
Large hop clover (*T. procumbens*)

DESCRIPTION OF SEED CHARACTERS

Trifolium agrarium L. Hop clover (Fig. 9)

Seeds about 1.2 mm. long and 0.8 mm. wide. Shape obovoid, apically asymmetrical. Radicle lobe 0.8–0.9 as long as seed, terminating against a distinct marginal notch, or less commonly flush with the margin. Furrow distinct, at least apically. Hilum oblique to subterminal, flush with the margin or slightly depressed. Surface dull. Terminal portion of seed generally yellowish, the basal yellowish-green.

Annual, adventive, and naturalized over a wide area in North America. It is said to have value as forage but is little planted commercially.

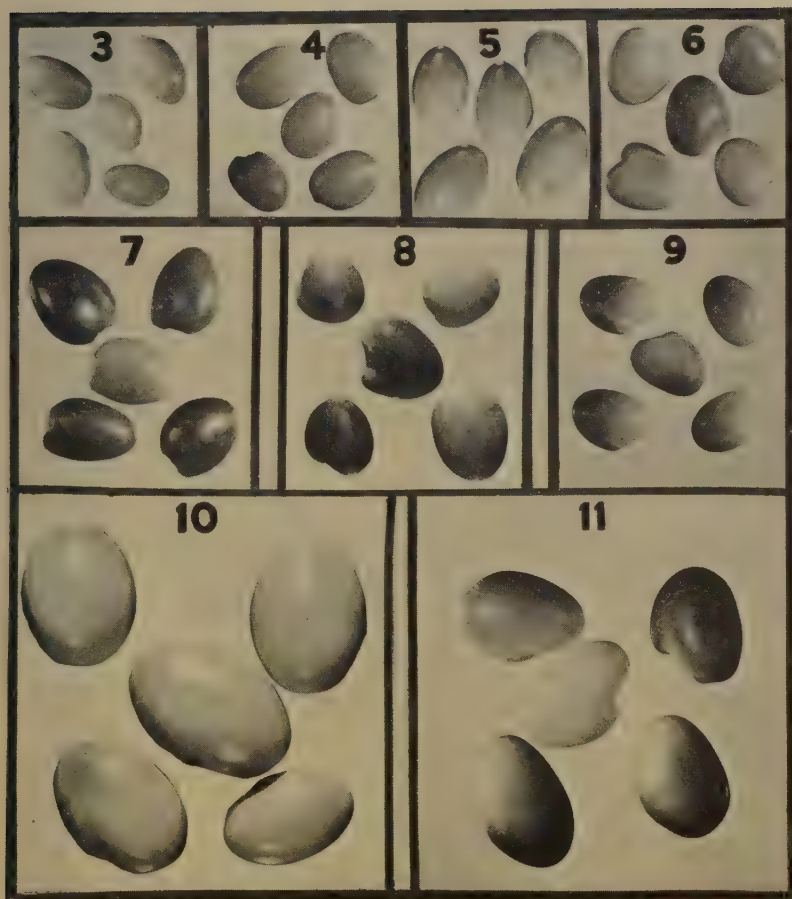
Trifolium arvense L. Rabbit's-foot clover (Fig. 4)

Seeds about 1 mm. long and 0.75 mm. wide. Shape ellipsoidal to obovoid; seeds plump, or if somewhat immature, flattened. Apex nearly symmetrical or evenly concave-curved on radicle side. Radicle lobe approximating or slightly shorter than seed. Furrow usually discernible, at least apically, and commonly darkened. Hilum obliquely subterminal, flush with the margin or depressed. Strophilar area glazed, somewhat umbonate, usually visible in side view as a short projection. Surface dull, commonly appearing finely punctate under magnification. Color a rather distinctive pale lemon-yellow or yellowish with a faint cast of green. Calyx fragments sometimes found with seeds are conspicuously long villous.

This adventive, annual clover is now a common weed in the southeastern United States.

Trifolium dubium Sibth. Suckling clover, Hop clover (Fig. 5)

Seeds approximately 1.2 mm. long and 0.8 mm. wide, occasionally somewhat smaller. Shape plump-ellipsoidal, nearly symmetrical. Immature seeds may be somewhat compressed and of a slightly greater



FIGS. 3-11. Seeds of common clovers. 10x.

3. *Trifolium procumbens*
 4. *T. arvense*.
 5. *T. dubium*.

6. *T. repens*.
 7. *T. resupinatum*.
 8. *T. hybridum*.

9. *T. agrarium*.
 10. *T. incarnatum*.
 11. *T. pratense*.

width and length than above indicated. Radicle lobe 0.75–0.85 as long as the seed, terminating nearly flush with the margin or marked by a slight concavity or notch. Furrow indistinct or absent. Surface shiny yellow, this color soon changing to orange-yellow or dull red with increasing age. Immature seeds are usually reddish-brown.

A widespread, naturalized annual, sometimes planted in the southern states as a component of pasture mixtures, particularly in combination with white clover.

Trifolium hybridum L. Alsike clover (Fig. 8)

Seeds mostly 1.2–1.3 mm. long and 0.8 mm. wide. Shape obovoid, usually nearly symmetrical. Apex truncate, notched. Radicle lobe slightly shorter than or nearly equaling length of seed. Furrow indistinct to distinct. Hilum terminal in apical notch. Surface nearly smooth, dull. Color ranging from dull black in fully mature seeds through various shades of greenish-black and olive green to greenish- or reddish-yellow in immature seeds. Distinctions between immature seeds of alsike and white clover are discussed under the latter on a subsequent page.

Alsike clover, introduced from northern Europe, is employed in the northern United States for the same purposes as red clover. It is more adaptable to varied soil types than red clover and is usually planted in areas where red clover does not thrive, or in pasture mixtures.

Trifolium incarnatum L. Crimson clover (Fig. 10)

Seeds approximately 2.4 mm. long and 1.8 mm. wide. Shape ellipsoidal, nearly symmetrical or slightly asymmetrical. Radicle lobe much shorter than seed, nearly even with the cotyledon margin at its terminus or contiguous to a slight notch. Furrow indistinct or absent. Hilum lateral, about two-thirds of the distance to apex, frequently with a well-developed collar. Strophilar area commonly conspicuous, frequently darkened, especially in old seeds. Surface relatively shiny, yellowish-orange, becoming reddish with age.

This European winter-annual clover is widely planted in the eastern and southeastern portions of the country and extends as far north as New Jersey. It is used for pasturage, green manure, and hay.

Trifolium pratense L. Red clover (Fig. 11)

Seeds 1.7–2 mm. long and 1–1.2 mm. wide, immature ones sometimes considerably smaller. Shape plump or somewhat compressed-ovoid, but strongly asymmetrical. Radicle lobe much shorter than cotyledonary lobe (0.4–0.8 mm. as long), quite variable in length and frequently somewhat divergently directed, the seeds thus characteristically being bilobed or "mitten shaped." Furrow usually indistinct or non-evident. Hilum lateral, slightly depressed in the angle at apex of radicle lobe. Surface relatively glossy, smooth. Seeds most commonly dark-purplish (or purple-black) at base and apically yellowish; the proportion of the surface which is characterized by one color and that which is marked by the other is

different for almost every individual seed and varies between the extremes of solid yellow and solid purple.

This is our most important clover from the agronomic standpoint. Like most of the others, it has been introduced from Europe. It is planted chiefly for hay and in crop rotation systems.

Trifolium prupcumbens L. Large hop clover, Hop clover (Fig. 3)

Seeds about 1.2 mm. long and 0.6 mm. wide, similar to *T. dubium* but narrower, and with a more distinct notch above radicle terminus. Hilum lateral to subterminal, usually in a distinct concavity.

Introduced from Europe and widely distributed in this country, although apparently not so common as other hop clovers. It is employed agriculturally to a slight extent in pasture mixtures for southern planting.

Trifolium repens L. White clover (including the varieties Ladino and Dutch clover) (Fig. 6)

Seeds about 1.0–1.1 mm. long and 0.7–0.8 mm. wide. Shape obovoid, nearly symmetrical to markedly asymmetrical, usually laterally compressed. Apex truncate to oblique-slanting or curved, usually notched or lobed. Radicle lobe most commonly nearly equaling seed length, but at times markedly shorter and somewhat divergently directed, then simulating shape of red clover. Immature seeds frequently somewhat angular. Furrow usually rather distinct. Hilum terminal in apical notch or sometimes laterally offset. Surface dull yellowish, turning orange-red with age; immature seeds are frequently tinged with green.

Immature seeds of white and alsike clover are frequently difficult to distinguish, both possessing a yellowish-green coloration and similar size and shape. Weisner (1940) indicates that differentiation between these seeds may be facilitated by noting the localization of the color—white clover exhibiting a yellowish tinge primarily on the radicle lobes, and alsike clover principally on the cotyledons. Observations by the writer indicate that reliance can frequently, but not invariably, be placed on this criterion.

Cultivated and wild strains of white clover cannot be distinguished by seed characters; neither can Ladino clover be determined on this basis. Munn (1940) and earlier authors (cited by him) report on a "picric acid test" for distinguishing between young seedlings of cultivated and wild strains of white clover. Brennand (1945) discusses the differences between plants of Ladino and White Dutch clover.

White clover, a native of Europe, is naturalized over nearly all temperate North America, besides being widely planted in pasture and lawn mixtures.

Trifolium resupinatum L. Persian clover (Fig. 7)

Seeds about 1.3 mm. long and 1 mm. wide. Shape obovoid; seeds apically truncate, usually emarginate, nearly symmetrical, slightly more curved on radicle side than opposing cotyledonary margin. Radicle lobe

nearly equaling or slightly exceeding cotyledonary one. Furrow absent or distinct, usually low and wide. Hilum terminal, slightly offset to the narrower radicle side. Surface smooth, shiny. Seeds, at maturity, dark, "oily-green" or almost black in color; incompletely immature seeds are usually light green or yellowish-green, or if shrunken and discolored, exhibiting various hues from reddish-brown to grey-purple.

A native of the Mediterranean region, this plant has been introduced into the southern states. It is a winter annual and is valuable for pasturage in late fall and early spring.

LESS COMMON CLOVERS (Figs. 12-18)

Egyptian clover or Berseem (*Trifolium alexandrinum* L.), an important agricultural crop in Egypt, is grown in this country on a limited basis. The seeds are somewhat similar to red clover in general appearance but are slightly larger, longer, less distinctly lobed, and of a uniform color.

Subterranean clover (*T. subterraneum* L.) has been experimentally planted in the United States. The seeds of this plant are quite distinctive, being large (2.5-4 mm. in length) and solid purple-black in color.

Strawberry clover (*T. fragiferum* L.), a native of Asia Minor, is said to have value for saline soils. The seeds have a shape somewhat similar to that of alsike clover but are longer and possess a dull, purplish-mottled coloration.

Seeds of Lappacea clover (*T. lappaceum* L.) are ovoid, relatively small, and characteristically possessed of a scurfy or cobwebby whitish covering about the seed coat.

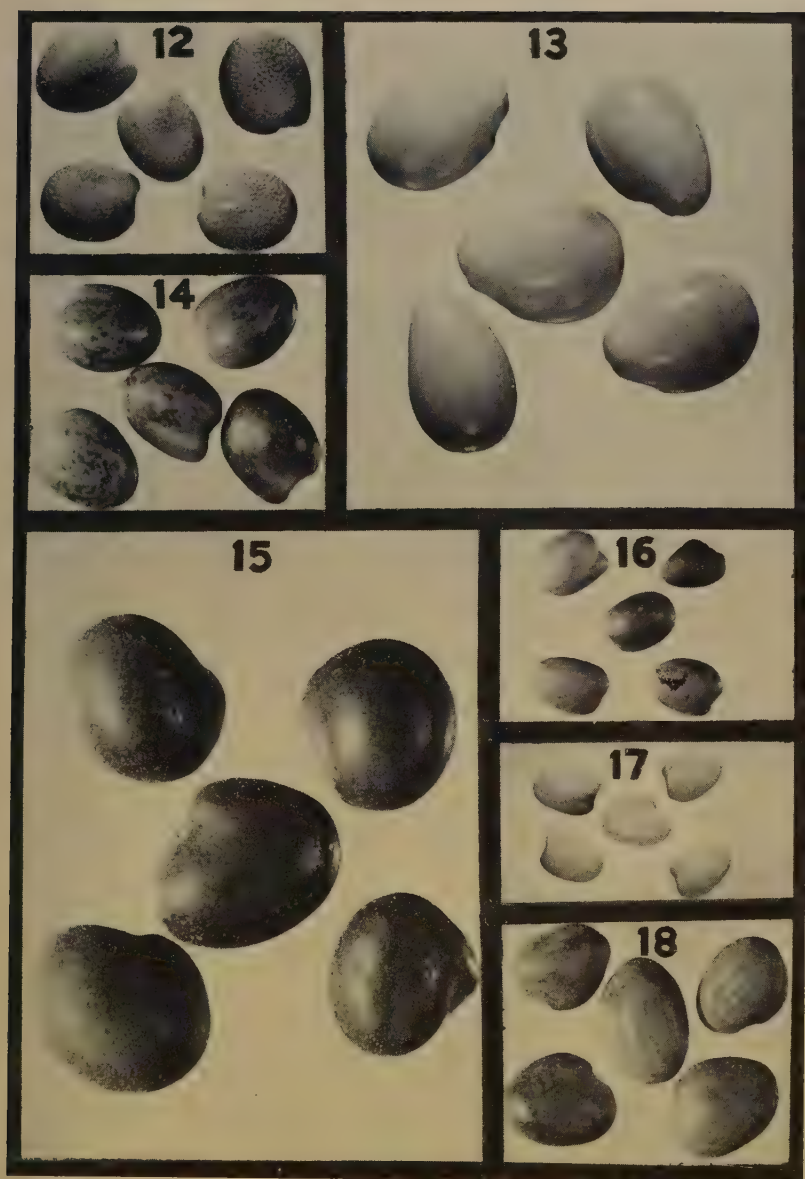
Teasel clover (*T. parviflorum* Lois.) seeds are of a shape and color similar to *T. agrarium* but may easily be distinguished by their distinctly warty appearance.

Crooked clover (*T. angulatum* Wald. and Kit.) seeds are quite small, dark, and finely warty.

Buffalo clover (*T. reflexum* L.) seeds possess a narrow radicle lobe equaling or slightly exceeding the cotyledonary one and are finely warty.

LITERATURE CITED

- BRENNARD, T. W.
1945. Field observation on Ladino-White Clover, White Dutch Clover. News Letter A.O.S.A. 19(5):9-10.
- HILLMAN, F. H., AND HELEN H. HENRY
1935. Photographs of drawings of seeds. U.S. Dept. Agri. Div. of Seed Investigations. Rev.
- ISELY, DUANE
1947. Seed characters of alfalfa and certain other species of *Medicago*. Iowa State College Jour. Sci. 21:153-59.
- MUNN, M. T.
1940. The picric acid test for distinguishing strains of White Clover. Contr. Handbook on Seed Testing. A.O.S.A.



FIGS. 12-18. Seeds of relatively uncommon clovers. 10x.

12. *Trifolium reflexum*.
13. *T. alexandrinum*.

14. *T. fragiferum*.
15. *T. subterraneum*.
16. *T. parviflorum*.

17. *T. angulatum*.
18. *T. lappaceum*.

MUSIL, ALBINA

1942. Testing farm seeds in home and school. U.S.D.A. Misc. Publ. 437. 88 pp.

WEISNER, MERLE

1940. Separation of immature seeds of *Trifolium repens*, White Clover, and *Trifolium hybridum*, Alsike Clover. Proc. A.O.S.A. 32:103-05.

FLORA OF ALASKA AND ADJACENT PARTS OF CANADA¹

An Illustrated and Descriptive Text of All Vascular Plants Known
to Occur Within the Region Covered

PART VII. GERANIACEAE TO PLUMBAGINACEAE

J. P. ANDERSON

From the Department of Botany, Iowa State College

Received May 5, 1948

23. GERANIACEAE (Geranium Family)

Herbs with stipulate leaves; flowers perfect, regular, axillary, solitary or clustered; sepals and petals usually 5 each; stamens distinct; anthers 2-celled, versatile; ovary of 5 carpels separating elastically at maturity with long styles attached to a central axis.

Carpels rounded, anthers 10.....1. *Geranium*
Carpels spindle-shaped, anthers 5.....2. *Erodium*

1. GERANIUM (Tourn.) L.

Leaves palmately lobed, cleft or divided; sepals and petals imbricated; ovary 5-lobed, 5-celled, beaked; style compound; ovules 2 in each cell but the carpels 1-seeded. (Greek, a crane, from the beaked fruit.)

1A. Perennials, petals 1 cm. or more long.

1B. Flowers bluish or rose-purple.....1. *G. erianthum*

2B. Flowers white.....2. *G. sanguineum*

2A. Annuals or biennials.

1B. Leaves divided to the base.....5. *G. robertianum*

2B. Leaves not divided entirely to the base.

1C. Beak short-pointed, inflorescence compact.....4. *G. carolinianum*

2C. Beak long-pointed, inflorescence loose.....3. *G. bicknellii*

1. *G. erianthum* DC.

Northern Geranium.

Stems appressed-pubescent, 2-8 dm. tall; leaves cordate to reniform in outline, 5- to 7-parted, the divisions lobed and toothed, pubescent on both sides or at least beneath, 5-15 cm. broad; sepals oblong, silky-pilose, ending rather abruptly in an awn 2-3 mm. long; petals 15-20 mm. long, pubescent at the base; style column 20-30 mm. long, finely villous.

¹Preceding parts of the paper were published in this Journal as follows: Part 1, Vol. XVIII, pp. 137-75, 1943; Part 2, Vol. XVIII, pp. 381-446, 1944; Part 3, Vol. XIX, pp. 133-205, 1946; Part 4, Vol. XX, pp. 213-57, 1946; Part 5, Vol. XX, pp. 297-347, 1946; Part 6, Vol. XXI, pp. 363-423, 1947.

Wet soil, especially alpine meadows, northeast Asia—south half of Alaska—B.C. Fig. 731.

2. *G. sanguineum* L.

Stems spreading, pubescent with widely spreading hairs, 2–4 dm. tall; leaves pentagonal in outline, 3–6 cm. broad, 3- to 7-parted, the divisions incised, ciliate-pubescent on the margins and the veins beneath; peduncles usually 1-flowered; sepals elliptic-lanceolate, ciliate on the margins and ribs, about 1 cm. long with an awn about 3 mm. long; petals white, 12–20 mm. long; style column in fruit 2 cm. or more long.

The plant here described differs from the typical form of Europe in the white flower, smaller leaves and more spreading habit. It may be a horticultural variety introduced many years ago at Sawmill Creek near Sitka where it was found by G. Turner and removed to the garden of the Alaska Pioneers Home at Sitka. Fig. 732.

3. *G. bicknellii* Britt.

Bicknell Crane's-bill.

Stem erect, 4–12 dm. tall and with ascending branches; leaves pentagonal or the lower orbicular in outline, divided nearly to the base, the divisions again cleft or incised, 2–6 cm. broad; peduncles usually 2-flowered; sepals lanceolate, ending in an awn 1–2 mm. long; petioles, peduncles, pedicels and sepals glandular-pubescent; petals about same length as the sepals, rose-purple.

Central Alaska—Lake Athabasca—Newf.—N. Y.—Utah—Wash. Fig. 733.

4. *G. carolinianum* L.

Carolina Crane's-bill

Somewhat resembling *G. bicknellii* but of lower, more spreading growth, 15–40 cm. tall; branches wide-spreading, especially from the base; leaves somewhat less divided than in the preceding.

An occasional introduced weed, B.C.—Ont.—Bermuda—Jamaica—Mex.—Calif.

5. *G. robertianum* L.

Herb Robert.

Stem weak, extensively branching, 15–45 cm. tall; leaves thin, the divisions lobed or toothed; peduncles 2-flowered, the pedicels divaricate; sepals awn-pointed; petals red-purple, about 1 cm. long.

Escaped at Juneau, Manitoba—N. S.—N. J.—Mo.

2. ERODIUM L'Her.

Stems generally with jointed nodes; flowers in axillary umbels, nearly regular; sepals usually awn-tipped; stamens 5, alternating with 5 staminodia; style column very elongate. (Greek, a heron, from the resemblance of the fruit to its beak.)

E. cicutarium (L.) L'Her.

Alfilaria.

Annual, branched, 15–40 cm. tall; leaves pinnate, the segments pin-natifid or incised; peduncles and pedicels more or less hirsute, the umbels

2- to 12-rayed; sepals 6-7 mm. long, sharp-tipped; petals slightly longer than the sepals, pink.

An occasional weed, adventive from Europe.

24. LINACEAE (Flax Family)

Herbs with alternate leaves; flowers perfect, regular, borne in racemes or panicles; stamens monodelphous; fruit a capsule opening by twice as many valves as there are carpels.

LINUM L.

Leaves narrow, sessile, entire; sepals 5, persistent; petals in ours blue or rarely white, fugaceous; stamens alternate with the petals, their filaments united at the base, each sinus with a short staminodium; styles 5; seed flat. (Classical Latin name.)

L. perenne L. ssp. *lewisii* (Pursh) Hult.

Lewis Wild Flax.

L. lewisii Pursh.

Stems 2-7 dm. tall, often several arising from a perennial woody root; leaves linear, ascending, sharply acute at apex, 1-3 cm. long; petals 15-20 mm. long.

Central Alaska—Victoria Land—Texas—northern Mex. Fig. 734.

25. BALSAMINACEAE (Jewel-weed Family)

Succulent herbs with swollen nodes; leaves simple; flowers irregular, perfect; sepals usually 3, the posterior one petaloid and strongly saccate or spurred; petals 5 or by union only 3; stamens 5, the anthers more or less united around the stigma; pod a 5-celled capsule, elastically dehiscent.

IMPATIENS L.

Lateral petals united with the posterior ones, hence 2-lobed; each cell of the capsule with few to several seeds, bursting violently when touched, which property is responsible for the name.

I. noli-tangere L.

Western Touch-me-not.

I. occidentalis Rydb.

Annual, stems light green, 6-12 dm. tall; leaves oval, thin, crenate-dentate, acuminate; lateral sepals acuminate, nerved; posterior sepal conic trumpet-shaped with curved spur, about 2 cm. long, pale yellow.

Bering Sea—central Alaska—Lake Athabasca—Wash. Also Eurasia. Fig. 735.

26. CALLITRICHACEAE (Water Starwort Family)

Small aquatic plants with capillary stems; leaves opposite, entire; flowers minute, axillary, perfect or monoeious; calyx none, but the flower usually subtended by 2 bracts; corolla none; stamen 1; anther 2-celled; styles 2, filiform; ovary 4-celled; fruit leathery, 4-lobed, 4-seeded.

CALLITRICHE L.

The only genus. (Greek, beautiful hair.)

1A. Fruit winged, leaves linear, all alike and submerged. .1. *C. autumnalis*

2A. Fruit not winged, floating leaves spatulate.

1B. Styles shorter than the fruit. 2. *C. verna*

2B. Styles longer than the fruit. 3. *C. bolanderi*

1. *C. autumnalis* L.

Northern Water-Starwort.

Leaves clasping at the base, retuse at the apex, 10–16 mm. long; fruit 1.5–2 mm. long, nearly as wide, its lobes separated by a deep groove, broadly winged on the margins.

Circumpolar, south to N. Y.—Colo.—Ore.

2. *C. verna* L.

Vernal Water-Starwort.

C. palustris L.

Stems usually floating, 2–30 cm. long; submerged leaves linear, 1-nerved, obtuse or emarginate at the apex, 8–25 mm. long; floating leaves ovate, usually crowded, petioled, 5–10 mm. long; fruit obovoid, about 1 mm. long and broad, slightly notched, grooved, keeled or slightly winged above.

Circumpolar, south to Florida and Calif. Fig. 736.

3. *C. bolanderi* Hegelm.

Bolander Water-Starwort.

Plants entirely aquatic; submerged leaves linear, notched at the apex, 12–50 mm. long; emersed leaves forming a rosette floating on the surface, roundish-ovate to spatulate, up to 1 cm. long; fruit obcordate, the semipersistent styles 1.25–2 times as long as the fruit. Resembles *C. verna*.

Alaska along the coast to Calif.

27. EMPETRACEAE (Crowberry Family)

Low evergreen heath-like shrubs; leaves small, narrow, channelled, nearly sessile, jointed at the base; flowers small, monoecious, dioecious or polygamous; sepals 3; petals 2 or 3 or none; stamens usually 3; anthers 2-celled; pistillate flowers with a 2- to several-celled ovary; fruit a berry-like drupe.

EMPETRUM L.

Depressed, branched, spreading shrub with densely leafy branches; flowers polygamous, axillary; sepals 3, petaloid; petals 3; stamens 3; ovary 6- to 9-celled; stigma with 6–9 toothed lobes; fruit with 6–9 nutlets. (Greek, upon a rock.)

E. nigrum L.

Crowberry.

Leaves linear-oblong, 4–7 mm. long, the groove on the lower surface caused by the revolute margins; flowers small, purplish; sepals and petals spreading; fruit globose, 4–6 mm. in diameter.

Very common throughout our area, circumboreal, south to the Great Lakes. Fig. 737.

28. ACERACEAE (Maple Family)

Trees or shrubs; leaves opposite, simple or compound; flowers perfect, polygamous, monoecious, or dioecious; sepals 4 or 5, rarely none, often colored; petals of same number, inserted on the margin of the indistinct disc, or none; ovary 2-celled with 2 ovules in each cell; fruit composed of 2 winged carpels united below.

ACER (Tourn.) L.

Leaves petioled, in ours more or less palmately cleft, lobed or parted; flowers polygamous or rarely perfect, in axillary or terminal racemes or corymbs; fruit or 2 samaras with reticulate wings. Most species in spring furnish a sweet watery sap. (Classical name.)

Mature carpels glabrous.....1. *A. glabrum* var. *douglasii*
 Mature carpels hairy.....2. *A. macrophyllum*

1. *A. glabrum* Torr. var. *douglasii* (Hook.) Dipp. Douglas Maple.
A. douglasii Hook.

Shrub or small tree up to 10 m. tall; twigs purplish or red; leaves long-petioled, 3-10 cm. long and broad, 3- to 5-lobed, sharply serrate, pale underneath, the lobes sharp-pointed; flowers yellowish-green, appearing with the leaves; samaras 25-35 mm. long the wings ascending.

Southeast Alaska—Alta.—Wyo.—Ore. Fig. 738.

2. *A. macrophyllum* Pursh. Broad-leaved Maple.

A tree 20-30 m. tall; leaves 1-3 dm. broad, cordate, deeply 5-lobed, the sinuses rounded; flowers appearing just before the leaves; sepals and petals about equal, greenish-yellow; samaras 35-45 mm. long.

Along the coast, southeast Alaska—Calif.

29. VIOLACEAE (Violet Family)

Low, usually perennial herbs (some tropical species shrubs); leaves simple, alternate or basal and with stipules; flowers perfect, irregular; sepals 5; petals 5, the lower one spurred and saccate at the base; stamens 5, the anthers united or connivent; ovary 1-celled with 3 parietal placentae; capsule loculicidal.

VIOLA (Tourn.) L.

Flowers solitary, scapose or axillary; the showy flowers produced early in the season and occasionally late in the fall; most species produce small, inconspicuous cleistogamous flowers through the summer which are far more productive of seed; sepals persistent, auricled at the base; two lower stamens with nectariferous projections extending into the

spur. The margins of the leaves in all our species are more or less crenate-dentate. (The Latin name.)

- 1A. Plant acaulescent or nearly so.
 - 1B. Plant with stolons..... 7. *V. epipsila repens*
 - 2B. Plant not stoloniferous.
 - 1C. Flowers white..... 6. *V. renifolia*
 - 2C. Flowers violet or lilac.
 - 1D. Petals beardless..... 8. *V. selkirkii*
 - 2D. Lateral petals only bearded..... 9. *V. langsдорфii*
 - 3D. All the petals bearded..... 5. *V. nephrophylla*
- 2A. Plants with evident stems.
 - 1B. Petals white on inner surface..... 3. *V. rugulosa*
 - 2B. Petals violet.
 - 1C. Leaves 10-25 mm. wide, spur long..... 10. *V. adunca*
 - 2C. Leaves 2-5 cm. wide, spur short..... 9. *V. langsдорфii*
 - 3B. Petals yellow.
 - 1C. Petals beardless..... 4. *V. biflora*
 - 2C. Petals bearded.
 - 1D. Stems 3-10 cm. long..... 2. *V. orbiculata*
 - 2D. Stems 10-30 cm. long..... 1. *V. nephrella*

1. *V. glabella* Nutt. Stream Violet.

Rootstock horizontal or nearly so; base leaves 1-3; stems 1-4, 2- to 4-leaved at the top; leaves reniform to broadly ovate, cordate at the base, short-pointed, nearly glabrous, 2-7 cm. wide; flowers axillary; corolla yellow with dark markings in the throat; spur saccate, short; seed dark, about 2 mm. long.

Aleutians—Mont.—Calif. Fig. 739.

2. *V. orbiculata* Geyer. Western Round-leaved Violet.

Rootstock stout and rough; basal leaves nearly round in outline, often pointed, with scattered hairs on upper surface; stems bearing somewhat reduced leaves and both petaliferous and cleistogamous flowers; stipules brown, scarious; seeds brown, 2 mm. long.

Near Ketchikan, B. C.—Mont.—Ore.

3. *V. rugulosa* Greene. Tall-stemmed White Violet.

Stems 2-6 dm. tall; basal leaves on long petioles, up to 1 dm. broad, broadly ovate to reniform, abruptly short-pointed, hairy beneath and sometimes on the veins above; stem leaves narrower and smaller; flowers axillary, the petals white with yellow base, often drying purplish; seeds brown, 2 mm. long. Produces underground runners.

Hot Springs, Liard River—Minn.—Iowa—Colo.—Wash.

4. *V. biflora* L. Two-flowered Violet.

Stems several from a rather short, fleshy rootstock, 2- to 3-leaved; leaves orbicular to reniform with hairy margins, 2-4 cm. wide; sepals narrow, ciliate; flowers small.

Bering Sea across Alaska and in Colo. and Eurasia. Fig. 740.

5. *V. nephrophylla* Greene. Northern Bog Violet.

Glabrous or nearly so; leaves ovate to reniform; petals large, bluish

violet with white, bearded bases; cleistogamous flowers on erect peduncles; seeds olive brown, 2 mm. long.

Hot Springs, Liard River—Newf.—Wis.—Colo.—Calif.

6. *V. renifolia* Gray.

Kidney-leaved White Violet.

Often pubescent throughout but may be glabrate, especially on upper surface of the leaves; leaves reniform, sometimes ending in a point; petals white, all beardless, the 3 lower veined with purple; cleistogamous flowers on horizontal peduncles until the capsule ripens. Our form is the var. *brainerdii* (Greene) Fern. which has the upper surface of the leaves glabrous.

Tyonek and Watson Lake—Labr.—Newf.—Penn.—Mich.—Colo. Fig. 741.

7. *V. epipsila* Ledeb. ssp. *repens* (Turcz.) W. Bckr.

Northern Marsh Violet.

V. achyrophora Greene.

V. palustris Auct.

Spring flowers 1 or 2, arising with the 1 or 2 leaves from the end of a creeping rhizome; leaves ovate to reniform; stipules glabrous, purplish, glandular-tipped; petals violet to lavender or white, with or without beards; seed less than 2 mm. long.

The species is circumpolar. Fig. 742.

8. *V. selkirkii* Pursh.

Great-spurred Violet.

5–10 cm. tall; leaves broadly ovate-cordate, the upper surface sparsely hairy, the basal sinus narrow; petals pale violet, the spur 3–5 mm. long with enlarged end; cleistogamous flowers on ascending peduncles.

Circumboreal but of very scattered distribution. Fig. 743.

9. *V. langsдорffii* Fisch.

Alaska Violet.

Glabrous; nearly stemless early in the season but with stems a few centimeters to one decimeter or more long later; leaves variable, reniform to oval, 2–5 cm. broad; stipules sharp-pointed, sometimes toothed; style small, beaked; corolla dark violet blue with short, light spur; petals 15–22 mm. long, the lateral ones bearded; capsules 10–15 mm. long. Our most showy violet.

Northeast Asia—central Alaska—Yukon—Calif. Fig. 744.

10. *V. adunca* Smith.

Hook-spurred Violet.

Stems from a woody rootstock, short at first flowering; leaves subcordate to ovate, obtuse, more or less finely puberulent, 1–3 cm. wide; stipules narrow and pointed with setulose teeth near the base; petals light to deep violet, 12–18 mm. long; spur 5–7 mm. long, hooked or straight; capsules brown-spotted.

Widely scattered, Kodiak Isl.—Great Bear Lake—Labr.—N. B.—N. Mex.—Calif. Fig. 745.

30. ELAEAGINACEAE (Oleaster Family)

Shrubs or trees with silvery, stellate or scaly pubescence; leaves entire; flowers perfect, polygamous or dioecious, borne in axillary clusters; hypanthium enclosing the ovary and becoming berry-like in fruit; sepals 4, deciduous; corolla none; stamens 4 or 8; ovary 1-celled, 1-ovuled; fruit a drupe.

Stamens 4, leaves alternate.....1. *Elaeagnus*

Stamens 8, leaves opposite.....2. *Shepherdia*

1. ELAEAGNUS (Tourn.) L.

Shrubs or trees; flowers in axillary clusters of 1-4, perfect or polygamous; perianth constricted over the top of the ovary, the upper part campanulate, four-lobed; stamens borne on the upper part of the perianth. (Greek, sacred olive.)

E. commutata Bernh.

Silverberry.

E. argentea Pursh.

A shrub 1-4 m. tall; leaves elliptic to ovate, 2-10 cm. long, silvery-scurfy on both sides; flowers fragrant, silvery on the outside, yellowish inside; fruit ellipsoid, silvery, 8-12 mm. long, dry and mealy, edible.

Central Alaska—Que.—Minn.—S. Dak.—Utah. Fig. 746.

2. SHEPHERDIA Nutt.

Shrubs with silvery or reddish-brown scaly or stellate pubescence; flowers small, borne in clusters at the nodes of the preceding season's twigs; perianth an 8-lobed disc, in the staminate flower the stamens alternate with the lobes of the disc. (John Shepherd was an English botanist.)

S. canadensis (L.) Nutt.

Soapberry, Soopolallie.

Lepargyrea canadensis (L.) Greene.

Branching shrub, 1-2 m. tall; young twigs and buds with reddish-brown scales; leaves ovate, 15-60 mm. long, sparingly stellate above, densely stellate-pubescent below mingled with brownish scales; flowers yellow; fruit red, 5-6 mm. long. Native Indians mix the berries with sugar and water and beat it into a froth much relished by them.

Noatak—Mackenzie delta—Newf.—N. Y.—Utah—Ore. Fig. 747.

31. ONAGRACEAE (Evening-Primrose Family)

Herbs (some exotic species shrubs); leaves simple; flowers perfect, axillary or borne in terminal racemes; hypanthium sometimes elongate, enclosing the ovary; sepals and petals usually 4; stamens as many or twice

as many as the petals; ovary usually 4-celled; fruit a capsule or nut-like.

Flowers 2-merous, fruit bristly.....1. *Circaea*
 Petals 4, stamens 8, fruit a many-seeded capsule.....2. *Epilobium*

1. CIRCAEA L.

Low slender perennials with succulent stems; leaves opposite, dentate, petioled; flowers small, white, borne in terminal and axillary racemes; sepals 2; petals 2, notched; fruit indehiscent, 1- to 2-celled; 1- to 2-seeded. (Circe of mythology was an enchantress.)

C. alpina L.

Enchanter's Nightshade.

Stem 5-25 cm. tall; leaves cordate, sharply dentate, 2-5 cm. long; pedicels 3-4 mm. long, reflexed in fruit; fruit narrowly obovoid, about 2 mm. long, covered with soft hooked hairs.

Wet woods, circumpolar, central Alaska south to Ga., Iowa, and Calif. Fig. 748.

2. EPILOBIUM (Gesn.) L.

Annuals or perennials; leaves sessile or short-petioled, entire or toothed; flowers perfect, solitary, axillary or borne in spike-like racemes; sepals 4; petals 4, purple, pink or white, in one species yellow, often notched; stigma club-shaped or 4-lobed; seeds numerous, each with a silky coma. Our species are all perennial by creeping horizontal stems, the latter sometimes shortened to form rosettes of thick, fleshy leaves at or near the base of the stem. The seeds of many species are finely papillose, but it takes a strong magnification to determine this character. Hybrids seem to occur. The small-flowered section constitutes a very confusing group. (Greek, upon a pod.)

1A. Leaves all alternate, flowers large and showy.

1B. Plant erect, high-growing..... 1. *E. angustifolium*

2B. Plant decumbent, lower-growing..... 2. *E. latifolium*

2A. At least some of the leaves opposite, flowers smaller.

1B. Petals yellow..... 3. *E. luteum*

2B. Petals pink, purple or white.

1C. Stigma 4-lobed..... 4. *E. treleaseanum*

2C. Stigma entire.

1D. Petals 3-5 mm. long.

1E. Leaves narrowly linear..... 5. *E. davuricum*

2E. Leaves wider.

1F. Plants less than 25 cm. tall.

1G. Stems simple, curved..... 6. *E. anagallidifolium*

2G. Stems usually branched..... 7. *E. leptocarpum*

2F. Plants usually more than 3 dm. tall.

1G. Leaves narrowly lanceolate or linear-

lanceolate, entire..... 8. *E. palustre*

2G. Leaves wider, thick, prominently

toothed..... 9. *E. adenocaulon*

2D. Petals 5-10 mm. long.

1E. Tall plants, up to 8 dm. tall..... 10. *E. glandulosum*

2E. Plants usually 2-4 dm. tall.

- 1F. Plants stoloniferous.
 1G. Leaves thick, middle stem leaves sessile,
 sharply toothed..... 11. *E. beringianum*
 2G. Leaves thin, the middle ones petioled,
 sparsely toothed..... 12. *E. lactiflorum*
 2F. Plants soboliferus.
 1G. Stems simple..... 13. *E. hornemannii*
 2G. Stems often branched..... 14. *E. sertulatum*

1. *E. angustifolium* L. Fireweed.

Chamaenerion angustifolium (L.) Scop.

C. spicatum (Lam.) S. F. Gray.

Stems usually simple, 5-25 dm. tall, glabrous below, puberulent above; leaves lanceolate or linear-lanceolate, paler beneath, 5-15 cm. long; flowers in terminal spike-like racemes; petals 10-18 mm. long, rose-purple or occasionally white or pink; style longer than the stamens, deeply cleft; capsule 5-8 cm. long.

Very common, circumpolar, south to N. Car., Texas, Ariz., and Calif. Fig. 749.

2. *E. latifolium* L. Dwarf Fireweed. Riverweed.

Chamaenerion latifolium (L.) Sweet.

Branched from the base, glabrate below, often canescent above, 1-5 dm. tall; leaves ovate-lanceolate, thick, pale, 2-7 cm. long, entire or with a few small teeth; inflorescence short; petals 15-25 mm. long, rose, pale purple or white; style shorter than the petals; capsule 5-8 cm. long. Favorite habitat is a sandy or gravelly deposit along streams.

Interrupted circumpolar in distribution, south to Gaspé Peninsula, Penn., S. Dak., Colo. and Ore. Fig. 750.

3. *E. luteum* Pursh. Yellow Willow-herb.

Decumbent or ascending, 2-8 dm. tall, the stems terete, glabrous below, pubescent on decurrent lines above; leaves sessile, ovate-lanceolate, glandular-toothed, 3-8 cm. long; inflorescence glandular-pubescent; sepals 1 cm. or more long; petals 12-18 mm. long, style exerted, stigma 4-lobed; capsule 4-6 cm. long.

Wet places, Aleutians—Alta.—Wash. Fig. 751.

4. *E. treleaseanum* Lévl. Trelease Willow-herb.

Stems about 2 dm. tall; leaves wide ovate, abruptly contracted at the base; capsule glabrous; petals pink. Resembles *E. luteum* except for flower color.

Rare, eastern Aleutians, Shumigan Isls. and Selkirk Mts., B. C.

5. *E. davuricum* Fisch. Davurian Willow-herb.

Stems simple, slender, 1-4 dm. tall; leaves 8-25 mm. long, 1-3 mm. wide; flowers few; petals pale, 2-3 mm. long; capsules erect, 3-5 cm. long, nearly glabrous when mature; seeds papillose.

Wet places, Seward Penin.—Baffin Land—Newf.—Hudson Bay, and in Eurasia. Fig. 752.

6. *E. anagallidifolium* Lam. Pimpernel Willow-herb.

Stem strongly curved when young, more erect at maturity, often tufted, 5–15 cm. tall, pubescent in decurrent lines; leaves 6–25 mm. long, oval, obtuse, narrowed into a short petiole, often with a few short teeth; flowers 1–5, grouped at the top, nodding; petals lilac or rose, 4–5 mm. long; capsules erect, 2–4 cm. long. Var. *pseudo-scaposum* (Hausskn.) Hult. is a form with long-peduncled capsules.

Circumpolar, south to Maine, Colo., and Calif. Fig. 753.

7. *E. leptocarpum* Hausskn. Thin-capsuled Willow-herb.

Stems 5–25 cm. tall, usually much branched, but in var. *macounii* Trel. nearly simple; leaves lanceolate, toothed, up to 25 mm. long; flowers one to several on each branch, usually many for the entire plant; petals 3–5 mm. long; capsules 2–4 cm. long on long peduncles; seeds papillose; coma dingy.

Aleutians—Ore. and in Newf. Fig. 754.

8. *E. palustre* L. Swamp Willow-herb.

Stems 2–6 dm. tall, simple or branched, canescent above with incurved hairs; leaves opposite below, often alternate above, narrow, 3–6 cm. long, usually shorter than the internodes; petals 3–5 mm. long, white or pink; capsule 4–8 cm. long, canescent; seed about 1 mm. long.

Circumpolar, south to Dela., Colo., and Wash. Fig. 755.

9. *E. adenocaulon* Hausskn. Northern Willow-herb.

A stout, usually branched, weedy plant 3–9 dm. tall, pubescent above, glandular in the inflorescence; leaves mostly lanceolate, the middle ones short-petioled, glandular-serrate, 3–8 cm. long; petals 3–4 mm. long; capsules slender, 3–8 cm. long; seeds papillose.

Central Alaska—Gt. Slave Lake—Newf.—Penn.—Mo.—N. Mex.—Ore. Fig. 756.

10. *E. glandulosum* Lehm. Glandular Willow-herb.

Stems stout, 3–9 dm. tall, somewhat angled, glabrate below, crisp-hairy and glandular above; leaves ovate or ovate-lanceolate, dentate, acute, sessile, 4–10 cm. long; petals purplish, 5–8 mm. long; capsule pubescent, 5–8 cm. long; seeds papillose.

North Asia—central Alaska—Labr.—Newf.—Gaspé Penin.—Wyo.—Ore. Fig. 757.

11. *E. beringianum* Hausskn. Bering Willow-herb.

Stems usually simple, glabrous except along the decurrent lines, often nodding at the apex, 2–4 dm. tall; leaves ovate, the lower ones

petioled, up to 45 mm. long, more or less toothed; petals rose-purple, pink or white, 6-9 mm. long; capsule nearly glabrous, up to 5 cm. long; seed smooth.

Along the coast, east Asia—Aleutians—St. Matthew Isl.—southeast Alaska and in Labr. and Newf. Fig. 758.

12. *E. lactiflorum* Hausskn.

Thin-leaved Willow-herb.

Stems simple, rather slender, 15-35 cm. tall; leaves distant, thin; ascending, entire or denticulate with small distant teeth, 2-4 cm. long, the middle ones petioled; petals about 5 mm. long, usually pink in our form; capsules 3-5 cm. long; seed smooth.

East Alaska—Greenl.—N. Hamp.—Colo.—Calif. and in Europe.

13. *E. hornemannii* Rchb.

Hornemann Willow-herb.

E. bongardii Hausskn.

Variable; stems usually unbranched, 1-3 dm. tall, pubescent along the decurrent lines; leaves ovate, obtuse, denticulate, or nearly entire, the middle ones petioled, 1-5 cm. long; flowers few; petals pink or rose-purple, 4-7 mm. long; pods erect, glabrous or nearly so, 4-6 cm. long; seeds papillose to nearly smooth.

Aleutians—Nome—Yukon—Minn.—Colo.—Calif. and Labr.—Newf.—N. Hamp. Also in Eurasia. Fig. 759.

14. *E. sertulatum* Hausskn.

Stems 12-30 cm. tall, often branched, pubescent along the decurrent lines; leaves ovate, petioled, often crowded at the top of the stem, more scattered below, rather thick and subcoriaceous, denticulate, 15-40 mm. long; petals about 5 mm. long; pod 3-5 cm. long, nearly glabrous to sparsely pubescent; seeds smooth.

Kamchatka—Nome—southeast Alaska—Aleutians.

32. HALORAGIDACEAE (Water-Milfoil Family)

Aquatic or marsh plants, mostly perennials with whorled leaves; flowers perfect or monoecious, borne in the axils of the leaves, in some cases appearing spicate; sepals 2-4; petals 2-4 and small, or wanting; stamens 1-8; ovary inferior, 1- to 4-celled; angled or winged; fruit a nutlet or drupe.

Leaves entire, stamens and styles each 1.....1. *Hippuris*

Leaves dissected, flowers 4-merous.....2. *Myriophyllum*

1. HIPPURIS L.

Calyx adherent to the ovary and with a minute, entire limb; petals none; style filiform, lying in a groove of the anther; fruit 1-celled, 1-seeded. (Greek, horse and tail.)

1A. Leaves linear or lanceolate.

1B. Leaves in whorls of 5-6, small, delicate alpine...1. *H. montana*

- 2B. Leaves in whorls of 5-12, aquatic.....2. *H. vulgaris*
 2A. Leaves obovate or oblanceolate.....3. *H. tetraphylla*

1. *H. montana* Ledeb. Mountain Mare's-tail.

Stems weak, 4-8 cm. tall; leaves linear, acute or mucronate, 3-8 mm. long, 1 mm. or less broad; flowers sometimes monoecious; fruit 1 mm. or less long, minutely granulate.

Wet alpine meadows, Aleutians—Wash. Fig. 760.

2. *H. vulgaris* L. Common Mare's-tail.

Stems usually partly immersed, 2-6 dm. long; leaves linear, acute, 1-2 cm. long on emerged stems, often much longer on the immersed parts of the stems; stamen with a short filament and a large anther opening by side slits; fruit ovoid, about 2 mm. long, minutely granulate.

Circumpolar, south to N. S., N. Y., N. Mex., Calif. Also in Patagonia and Tierra del Fuego. Fig. 761.

3. *H. tetraphylla* Lf Four-leaved Mare's-tail.

Stems 1-4 dm. long; leaves obovate or oblanceolate, entire, in whorls of 4-6, 8-16 mm. long; fruit rugose, about 2 mm. long.

Circumpolar, south to Gaspé Penin., Hudson Bay, B. C. Fig. 762.

2. MYRIOPHYLLUM (Vaill.) L.

Stems slender, usually floating; immersed leaves finely dissected into filiform divisions, the emerged ones entire or pectinately lobed; flowers axillary or in terminal spikes, the upper staminate, the lower pistillate, the intermediate perfect; stamens 4-8; ovary 2- to 4-celled with 1 ovule in each cavity. (Greek, myriad-leaved.)

Floral bracts verticillate.....1. *M. spicatum*

Floral bracts alternate.....2. *M. alterniflorum*

1. *M. spicatum* L. Spiked Water-Milfoil.

Stems 2-10 dm. long; leaves verticillate in 4's or 5's, pinnatifid into fine capillary divisions; floral leaves ovate, toothed or more often pectinately pinnatifid, 1-2 times the length of the flowers; flowers in an interrupted spike; petals 4, deciduous; fruit about 3 mm. broad, slightly broader than long; carpels rounded on the back. Most of our material belongs to the form described as *M. exalbescent* Fern. (*M. spicatum* ssp. *exalbescent* [Fern.] Hult.) in which the stems have a tendency to whiten on drying.

Circumpolar, south to Mass., Ga., Colo., and Calif. Fig. 763.

2. *M. alterniflorum* DC. Loose-flowered Water-Milfoil.

Submerged leaves in whorls of 3-5, usually less than 1 cm. long; floral leaves ovate or linear, entire or minutely toothed, smaller than the flowers.

Reported from the Buckland River and Mackenzie District. Otherwise known from Greenland to Mass. and Minn.

33. ARALIACEAE (Ginseng Family)

Aromatic herbs, shrubs or trees; leaves alternate or whorled, simple or compound; flowers regular, perfect or polygamous, inconspicuous; sepals 5; petals and stamens usually 5 each; ovary 2- to 5-celled; ovules solitary in each cavity; fruit a berry or drupe.

Herb, leaves compound..... 1. *Aralia*
Prickly shrub, leaves simple..... 2. *Oplopanax*

1. ARALIA (Tourn.) L.

Perennial herbs, shrubs or trees; leaves pinnately or ternately decompound; flowers in a compound umbel in our species; calyx truncate or 5-toothed; styles 5; fruit a small berry enclosing up to 5 seeds.

A. nudicaulis L.

Wild Sarsaparilla.

Nearly acaulescent with a long rootstock; leaf 1, ternate, divisions each bearing 3-5 leaflets; leaflets acuminate, finely serrate, 5-13 cm. long; scapes shorter than the leaves, bearing a compound umbel with 3-5 primary rays; flowers greenish; fruit globose, black, 5-lobed when dry.

Woods, Hot Springs of the Liard River—Mack.—Newf.—Ga.—Colo.—Idaho—B. C.

2. OPLOPANAX Miq.

Very prickly shrubs; leaves large, palmately lobed; flowers in paniced umbels; calyx teeth nearly obsolete; petals 5, greenish; stamens 5, the filaments filiform, the anthers oblong; ovary bicarpellary; fruit flattened.

O. horridum (Sm.) Miq.

Devil's Club.

Echinopanax horridum (Sm.) Dec. & Planch.

Fatsia horrida (Sm.) B. & H.

A straggling shrub 1-5 m. tall, armed with numerous prickles; leaves orbicular in outline with prickles on the petiole and veins, 2-7 dm. wide, palmately 3- to 7-lobed, further incised, sharply and unevenly serrate, cordate at the base; inflorescence terminal, 1-3 dm. long; fruit scarlet, 5-7 mm. long.

Japan and Korea—south central Alaska—Mich.—Mont.—Ore. Fig. 764.

34. AMMIACEAE (Carrot Family)

Herbs, usually with hollow stems; leaves compound or decompound, rarely simple, the petioles dilated at the base and sheathing the stem; flowers small, perfect or polygamous, in simple or compound umbels, the umbels usually subtended by bracts forming involucre for the primary umbels and involucre for the secondary umbels; calyx adhering to the ovary, its limb 5-toothed or obsolete; petals 5; stamens 5, inserted on the epigenous disc; anthers versatile; pistils of 2 united carpels, each

1-ovuled, the 2 distinct styles borne on more or less thickened bases (stylopodia); fruit of 2 distinct carpels separating at maturity; the inner faces form the commissure; each carpel usually with 5 primary ribs and often secondary ribs between them, the space between them called the intervals. The pericarp usually has oil tubes in the intervals and on the commissural side. Some of the ribs are often winged. This family is often known as the UMBELLIFERAE. Determinations are easiest with mature fruit.

- 1A. Fruit bristly.
 - 1B. Fruit globose or ovoid..... 1. *Sanicula*
 - 2B. Fruit linear..... 2. *Osmorrhiza*
- 2A. Fruit smooth or slightly pubescent.
 - 1B. Leaves reduced to hollow, septate petioles..... 3. *Lilaeopsis*
 - 2B. Leaves normal.
 - 1C. Leaves simple, linear-lanceolate..... 4. *Bupleurum*
 - 2C. Leaves compound.
 - 1D. Fruit flattened dorsally (parallel to the commissure).
 - 1E. Flowers yellow..... 5. *Pastinaca*
 - 2E. Flowers white.
 - 1F. Leaf segments small.
 - 1G. Fruit 4-6 mm. long..... 6. *Conioselinum*
 - 2G. Fruit 2.5-3 mm. long..... 7. *Cnidium*
 - 2F. Leaf segments large.
 - 1G. Plant pubescent..... 8. *Heracleum*
 - 2G. Plant glabrous or nearly so..... 9. *Angelica*
 - 2D. Fruit terete or only slightly compressed.
 - 1E. Stems erect or ascending.
 - 1F. Ribs of fruit thick and corky..... 9. *Angelica*
 - 2F. Ribs of fruit thin and acute..... 10. *Ligusticum*
 - 2E. Stems prostrate or spreading.
 - 1F. Plant tomentose..... 11. *Glehnia*
 - 2F. Plant glabrous or nearly so..... 12. *Oenanthe*
 - 3D. Fruit flattened laterally.
 - 1E. Leaves decompound..... 13. *Cicuta*
 - 2E. Leaves simply pinnate..... 14. *Sium*

1. SANICULA (Tourn.) L.

Glabrous perennials; leaves alternate, palmately 3- to 7-lobed; flowers yellowish, in irregularly compound few-flowered umbels; calyx teeth foliaceous, lanceolate; fruit globose or ovoid, without ribs but covered with hooked bristles. (Latin, to heal.)

S. marylandica L.

Black Snakeroot.

Stems 3-12 dm. tall; basal leaves large, long petioled, 3- to 5-divided to the base and the lateral divisions 2-cleft, all divisions irregularly serrate or dentate, often incised; pistillate flowers sessile, the staminate pedicelled; fruit 6-7 mm. long.

Hot Springs, Liard River—Newf.—Ga.—Colo.—Wash.

2. OSMORRHIZA Raf.

Perennials from aromatic, clustered, fleshy roots; leaves ternately decompound; leaflets ovate or lanceolate, toothed or incised; involucre and involucels small or obsolete; umbels few-rayed, long-peduncled;

calyx teeth obsolete; stylopodium conic; fruit narrow, attenuate at the base, bristly on the ribs; oil tubes obsolete. (Greek, a scent and root.)

1A. Fruit clavate.....1. *O. obtusa*

2A. Fruit beaked.

1B. Beak short, flowers purplish.....2. *O. purpurea*

2B. Beak about 2 mm. long, flowers white or greenish. 3. *O. chilense*

1. *O. obtusa* (Coul. & Rose) Fern. Blunt-fruited Sweet-Cicely.
Washingtonia obtusa Coul. & Rose.

Stems 2-7 dm. tall; leaves biternate or ternate-pinnate; leaflets 15-50 by 10-30 mm., rays of the umbels 2-5, divergent or reflexed, 2-5 cm. long; pedicels 2-5, divergent, 10-35 mm. long; fruit 12-17 mm. long, obtuse or abruptly acute at the apex, densely hispid at the base.

Central Pacific coast of Alaska—Labr.—Newf.—Colo.—Ariz.—Calif. Fig. 765.

2. *O. purpurea* (Coul. & Rose) Suksd. Sitka Sweet-Cicely.
Washingtonia purpurea Coul. & Rose.

Stems rather slender, 2-7 dm. tall; leaves 1- to 3-ternate; leaflets lanceolate to ovate, 15-70 by 5-40 mm., acute or acuminate, serrate to incised or lobed, usually hispidulous on the veins and margins; rays of the umbel 2-6, 20-75 mm. long; pedicels 5-25 mm. long; flowers purple or greenish-purple; styles 0.5-1 mm. long; fruit 10-13 mm. long, hispid at base only.

Kodiak along the coast to Oregon. Fig. 766.

3. *O. chilense* Hook. & Arn. Chile Sweet-Cicely.
Washingtonia divaricata Coul. & Rose.

Stems 3-10 dm. tall; foliage somewhat pubescent or nearly glabrous; leaflets thin, 2-8 cm. long; umbels 3- to 7-rayed; fruit strongly beaked at the top, 12-20 mm. long, densely hispid at the base.

Aleutians—Que.—N. Hamp.—Colo.—Ariz.—Calif. and in temperate South America. Fig. 767.

3. LILAEOPSIS Greene.

Small, creeping, glabrous perennial; flowers white, in simple umbels on scapes; fruit globose, somewhat flattened laterally; lateral ribs corky-thickened. (Greek, resembling the genus *Lilaea*.)

L. occidentalis Coul. & Rose.

Stems rooting at the nodes; leaves 2-4 cm. long, linear, terete; peduncles shorter than the leaves; umbels 5- to 12-rayed; fruit ovoid, 2 mm. long.

Reported from southern Alaska but the report needs confirmation. Vancouver Isl.—central Calif.

4. BUPLEURUM L.

Leaves simple, entire, clasping or perfoliate; involucre present in our species; involucels of 5 or more conspicuous ovate bractlets; calyx teeth obsolete; stylopodium flat, prominent; style short; fruit oblong, flattened laterally, with slender equal ribs. (Greek, ox-ribbed, from the veining of the leaves, not evident in our species.)

B. americanum Coult. & Rose.

American Thorough-wort.

Perennial with a woody caudex; stems 1-3 dm. tall; basal leaves linear-lanceolate, 4-15 cm. long with parallel veins; stem leaves lanceolate and clasping; involucre and involucels prominent; flowers yellow or purplish; fruit oblong, $3-4 \times 2-2.5$ mm.

Bering Sea—Yukon and in south Alta., Mont., Idaho, Wyo. Fig. 768.

5. PASTINACA L.

Tall glabrous biennial; leaves pinnate, the leaflets broad; flowers yellow, in large compound umbels; fruit oval, much flattened dorsally, the lateral ribs broadly winged. (Latin, *pastus*, food.)

P. sativa L.

Common Garden Parsnip.

Root fleshy, fusiform; stems stout, 5-15 dm. tall, grooved; leaflets ovate or oval, sessile, dentate and usually lobed, 2-10 cm. long; fruit $5-7 \times 4-6$ mm.

Naturalized at Manly Hot Springs. Native of Europe but widely introduced as a weed.

6. CONIOSELINUM Fisch.

Tall, stout, glabrous perennials with thick roots; leaves ternate, then pinnately decompound, the leaflets lobed or toothed; flowers white, in compound umbels; involucre small or wanting; involucels composed of narrow, linear bractlets; calyx-teeth obsolete; stylopodium slightly conic; fruit flattened dorsally or nearly terete; ribs prominent. (*Conium* and *Selinum* are related genera.)

Lateral wings of the fruit much longer than the dorsal... 1. *C. benthami*
All the ribs with wings nearly equal..... 2. *C. cnidifolium*

1. *C. benthami* (Wats.) Fern.

Western Hemlock-Parsley.

C. gmelini Coult. & Rose, not Steud.

Stems from tapering roots, 5-12 dm. tall; glaucous below but strigose in the inflorescence; ultimate leaf segments variable but broader than in *C. cnidifolium*; bractlets linear-subulate, longer than the pedicels; fruit 5-6 mm. long. A low form in the Bering Sea region is only 1-3 dm. tall. May not be specifically distinct from *C. chinense* (L.) B.S.P.

Along the coast, east Asia—Point Hope and the Aleutians to Ore. Fig. 769.

2. *C. cnidifolium* (Turcz.) Pors. Dawson Hemlock-Parsley.
C. dawsonii Coult. & Rose.

Stems 4-10 dm. tall; ultimate leaf segments small and narrow with acute tips; bracts with foliose divided tips, deciduous; bractlets longer than the pedicels, ending in a long attenuation; fruit 4-5 mm. long.

Siberia across Alaska to Mackenzie. Fig. 770.

7. CNIDIUM Cusson.

Stems from slender taproots, slender, erect and branching; leaves pinnately dissected; petioles sheathing; inflorescence of loose compound umbels; involucre usually wanting; involucels of several slender bractlets; rays numerous; flowers white; petals obovate with inflexed tips; fruit ovoid, slightly flattened dorsally; ribs prominently corky-winged.

- C. ajanense* (Reg. & Tiling) Drude.

Leaves resembling *Conioselinum* but less complex and ovate in outline; lateral wings of the carpels markedly longer than the dorsal; involucels usually shorter than the pedicels.

Central Yukon River district and eastern Asia.

8. HERACLEUM L.

Tall, stout, leafy-stemmed perennial; leaves large, ternately compound; leaflets large and broad; flowers white, borne in large compound umbels; calyx teeth small or obsolete; stylopodium conic; fruit flattened dorsally, obovate, the lateral ribs with broad wings. (Named for Hercules of mythology.)

- H. lanatum* Michx. Cow Parsnip.

Very stout, 10-25 dm. tall, tomentose-pubescent; leaflets 1-3 dm. broad, stalked, palmately cleft and incised; base of petiole much dilated and wooly; bractlets subulate; fruit ovate or obcordate with conspicuous oil tubes, 9-12 mm. long.

East Asia—Alaska—Lake Athabaska—Labr. — Ga. — Ariz. — Calif. Fig. 771.

9. ANGELICA L.

Ours stout, fistulose perennials from stout taproots; leaves ternately-pinnately compound, the leaflets broad, sometimes lobed; inflorescence of large, compound umbels; flowers white, pinkish or greenish; calyx teeth minute or obsolete; fruit somewhat flattened dorsally. (Named for supposed medicinal virtues.)

Oil tubes numerous, seed free in the pericarp at maturity. 1. *A. lucida*
 Oil tubes few, seed adhering to the pericarp..... 2. *A. genuflexa*

1. *A. lucida* L. Sea Coast Angelica.
Coelopleurum gmelini (DC.) Ledeb.

Stems leafy, 5–12 dm. tall; leaves mostly tri-ternate, the petioles with much-inflated bases; leaflets rather thick, mostly ovate, coarsely and unevenly serrate, 3–8 cm. long; rays up to 50 or more; fruit ellipsoid, 7–9 mm. long; pedicels 8–16 mm. long.

East Asia across Alaska and Yukon to Labr.—N. Y.—Calif. Fig. 772:

2. *A. genuflexa* Nutt.

Bent-leaved Angelica.

Stems 4–18 dm. tall, glabrous below the inflorescence; leaves ternate or biternate, the divisions pinnate, the primary divisions usually strongly deflexed; leaflets ovate or lanceolate, acuminate, irregularly but sharply serrate, 3–8 cm. long; fruit oblong, 4–5 mm. long.

Mostly along the coast, east Asia to Calif. Fig. 773.

10. *LIGUSTICUM* L.

Glabrous perennials; bracts often deciduous; bractlets narrow; stylopodium conical; fruit oblong or ellipsoid, only slightly flattened laterally; ribs all prominent and nearly equal. (Named for Liguria in Italy.)

Low alpine plant, leaves pinnate.....1. *L. mutellinoides*

Tall marine plant, leaves biternate.....2. *L. hultenii*

1. *L. mutellinoides* (Crantz) Willar ssp. *alpinum* (Ledeb.) Thellung.

L. macounii Coult. & Rose.

Podistera macounii Mathias & Constance.

Leaves 4–10 cm. long including the petioles; leaflets 3–7, broadly ovate, 2- to 3-lobed, again cleft or toothed, 3–15 mm. long; flowers yellowish-green, in few-rayed umbels; bracts and bractlets rather narrow and only occasionally toothed; pedicels very short; fruit ovoid, 3–4 mm. long.

Eurasia, in Alaska from Bering Sea to Eagle. Fig. 774.

2. *L. hultenii* Fern.

Hultén Sea Lovage.

L. scoticum of reports.

Stems more or less branched, 2–7 dm. tall; leaves mostly biternate, thick; leaflets broadly ovate, 15–60 mm. long, coarsely serrate; inflorescence glabrous; flowers white or pinkish; rays 2–5 cm. long; pedicels 5–10 mm. long; fruit oblong, 6–10 mm. long. Closely related to *L. scoticum* of the Atlantic coasts and may be only a geographic race of that species.

East Asia and the coasts of Alaska south to Vancouver Island. Fig. 775.

11. *GLEHNIA* Schmidt.

Low, spreading or prostrate, subcaulescent, pubescent perennials; leaves coriaceous, once or twice ternate or ternate-pinnate; leaflets oblong-ovate or cuneate with crenate-dentate margins; flowers white, the calyx teeth inconspicuous; fruit globose to ovoid-oblong, the ribs all corky-winged, the wings broadest at the base.

G. littoralis Schmidt ssp. *leiocarpa* (Mathias) Hult.

G. leiocarpa Mathias.

Leaflets $5-50 \times 4-30$ mm., hirtellous on the rachis and nerves above, tomentose beneath; inflorescence densely villous, usually shorter than the leaves; fruit 4-12 mm. long, nearly glabrous.

Port Hobron to Calif., the species in east Asia.

12. OENANTHE L.

Glabrous aquatic or marsh plants; leaves bipinnate or ternate-pinnate; flowers white, borne in compound umbels; calyx lobes evident; stylopodium conical or hemispherical; petals lobed or with an inflexed point; fruit ellipsoidal, terete, or slightly flattened laterally; oil tube solitary in the intervals, 2 on the commissural side. (Greek, wine and flower.)

O. sarmentosa Presl.

Water Parsley.

Stems weak and reclining, 5-10 dm. long; leaflets ovate or lanceolate in outline, 1-5 cm. long, deeply toothed; rays 4-angled; bracts few; bractlets many, narrow; fruit short-pedicelled, 2.5-3.5 mm. long.

Along the coast, south Alaska—central Calif. Fig. 776.

13. CICUTA L.

Tall, stout, glabrous or glaucous, poisonous perennials with short, more or less chambered rootstocks; leaves pinnate or pinnately compound; leaflets serrate; flowers white, borne in large, compound umbels; bracts few or none; bractlets several, slender; calyx teeth prominent, acute; stylopodium low; fruit flattened laterally; ribs corky, the lateral strongest; oil-tubes solitary in the intervals, 2 on the commissural side. The poison is largely concentrated in the rootstocks and seed. (The ancient Latin name.)

1A. Fruit oblong, longer than wide.....1. *C. maculata*

2A. Fruit orbicular, leaflets ovate to lanceolate.....2. *C. douglasii*

3A. Fruit shorter than wide, leaflets linear or linear-lanceolate.....3. *C. mackenziana*

1. *C. maculata* L.

Spotted Water Hemlock.

Stems 10-25 dm. tall; leaves bipinnate; leaflets sharply serrate, 3-8 cm. \times 5-20 mm.; fruit about 3.25×2.75 mm., not constricted at the commissure; pedicels 5-15 mm. long.

Central Alaska—Que.—N. Car.—Texas. Fig. 777.

2. *C. douglasii* (DC.) Coult. & Rose.

Western Water Hemlock.

Stems 8-20 dm. tall; leaves usually bipinnate; leaflets ovate or lanceolate, deeply serrate to incised, 3-10 cm. long, veins prominent beneath; fruit 2-2.5 mm. long and wide, constricted at the commissure.

South Alaska—Alta.—Mont.—N. Mex.—Calif. Fig. 778.

3. *C. mackenziana*

Mackenzie Water Hemlock.

Stems 5-15 dm. tall; leaves once to thrice pinnate; leaflets linear-lanceolate, 3-10 cm. \times 2-10 mm., remotely serrate with forward-pointing teeth; fruit about 2 mm. long, 2-2.5 mm. wide, constricted at the commissure.

Bering Sea—Mackenzie. Fig. 779.

14. *SIUM* (Tourn.) L.

Perennial marsh plants; leaves pinnate; leaflets serrate or pinnatifid; flowers in large compound umbels; involucre and involucels of numerous narrow bracts and bractlets; fruit oval in outline, glabrous, with prominent and corky ribs. (Greek name of a marsh plant.)

S. suave Walt.

Hemlock Water Parsnip.

S. cicutaeifolium Schrank.

Stems stout, 6-15 dm. tall; leaflets linear or lanceolate, sharply serrate, 3-10 cm. long, or if growing in water more or less dissected; fruit ovate, about 3 mm. long.

Collected at Galena, east Asia—Newf.—Va.—central Calif.—B. C. Fig. 780.

35. **CORNACEAE (Dogwood Family)**

Herbs, shrubs or trees; leaves simple, alternate, opposite or whorled, usually entire; flowers perfect or unisexual, usually borne in cymes or heads; calyx adherent to the ovary, the flowers 4- or 5-merous; fruit a drupe, the stone 1- or 2-celled, 1- or 2-seeded.

CORNUS (Tourn.) L.

Flowers perfect, small, white or purplish; calyx small, 4-toothed; fruit a white or red drupe. (Greek, horn, from the toughness of the wood of some species.)

1A. Shrub, flowers in cymes.....3. *C. stolonifera*

2A. Perennial herbs, flowers in heads subtended by white petaloid involucral bracts.

1B. Leaves whorled at the summit of the stem.....1. *C. canadensis*

2B. Leaves opposite.....2. *C. suecica*

1. *C. canadensis* L.

Bunchberry.

Stems 1-3 dm. tall from creeping rootstocks, with a whorl of 6 leaves at the summit and occasionally 1 or 2 pairs of smaller leaves or bracts below; leaves ovate or oval, acute at both ends, 3-7 cm. long, the two opposite ones being larger and broader than the intermediate ones; floral bracts usually 4, white or sometimes blotched with red; petals white or purplish, one of them bristly-tipped; fruit a bunch of orange-red drupes; stone globose.

Very common, east Asia and all the northern part of North America south to Va. and Calif. Fig. 781. Where the range of this species overlaps

the range of the next, hybrids are found. These are intermediate between the two species and were described as *C. unalaskensis* Ledeb.

2. *C. suecica* L.

Lapland Cornel.

Leaves usually 3 pairs below the inflorescence, 2- to 6-leaved branches later arising on either side of the peduncle; leaves smaller than in *C. canadensis*, 5- to 7-veined; floral bracts usually 4, ovate; petals dark purple; drupes globose or ovoid, rose-red; stone slightly flattened and channeled on both sides.

Distribution interrupted circumpolar south to Que. and Calif. Fig. 782.

3. *C. stolonifera* Michx.

Red Osier Dogwood.

C. stolonifera var. *baileyi* (Coult. & Evans) Drescher.

Svida instolonea A. Nels.

A branching shrub 1-3 m. tall; young branches and inflorescence appressed-pubescent; leaves only slightly paler beneath, thin, oval, ovate or elliptic, entire, acute or acuminate, strigose on both sides; corolla white; petals about 3 mm. long; fruit white; stone flattened, about 5 mm. long.

Central Alaska—Labr.—Newf.—Va.—Mexico—Calif. Fig. 783.

36. PYROLACEAE (Wintergreen Family)

Rather low, evergreen perennials; leaves thick and leathery, usually clustered at the base of the stems; flowers perfect, often slightly irregular; sepals 4 or 5, persistent; corolla of 4 or 5 wax-like petals; stamens twice as many as the petals; ovary superior, 4- to 5-celled; styles united; stigmas 5-lobed; capsule loculicidal with many minute seeds.

1A. Stems leafy, style very short.....1. *Chimaphila*

2A. Stems scapose, styles evident.

1B. Flowers solitary.....2. *Moneses*

2B. Flowers borne in racemes.....3. *Pyrola*

1. CHIMAPHILA Pursh.

Stems decumbent with ascending leafy branches; leaves opposite or whorled, thick and shining; flowers borne in terminal corymbs; petals 5, orbicular, concave; capsule erect, globose, 5-celled. (Greek, winter-loving, from the evergreen leaves.)

C. umbellata (L.) Bart. ssp. *occidentalis* (Rydb.) Hult.

Pipsissewa, Prince's Pine.

Stems 1-2 dm. tall; leaves whorled, oblanceolate, cuneate at the base, rounded or acute at the apex, sharply serrate, 3-7 cm. long; flowers 3-7; petals reddish; capsule depressed-globose, 5-6 mm. in diameter.

Southeast Alaska—N. S.—Ga.—Mex.—Calif. Fig. 784.

2. MONESES Salisb.

Low glabrous perennial; rootstock slender; leaves coriaceous, serrate, crowded at the end of the stem; flower nodding at the end of a long

peduncle; petals white or tinted rose; ovary globose; stigma peltate, usually 5-lobed; capsule subglobose. (Greek, single-delight.)

M. uniflora (L.) Gray.

Single Delight. Wax Flower.

Pyrola uniflora L.

Peduncles 4–12 cm. long; leaf blades 5–15 mm. long, crenate, rounded at the tip, rounded or cuneate at the base; sepals ovate, ciliolate, about 3 mm. long; petals ovate, 6–9 mm. long; capsule 6–8 mm. in diameter. A robust form with leaves 8–25 mm. in diameter has been described as *M. reticulata* Nutt. It may be regarded as a variety.

Woods, circumboreal south to Penn.—Colo.—Calif. Fig. 785.

3. PYROLA (Tourn.) L.

Glabrous perennials with stoloniferous rootstocks; leaves thick, mostly basal; flowers in racemes, nodding; sepals 5, petals 5, concave, deciduous, spreading or connivent; anthers erect in bud, emarginate or 2-beaked at the base and generally reversed at flowering time; ovary 5-celled; stigma 5-lobed; fruit a 5-lobed capsule opening from the base. (Latin, diminutive of *Pyrus*, the pear, in reference to the leaves.)

1A. Style curving, stigma narrower than the style.

1B. Sepals little if at all longer than broad..... 1. *P. chlorantha*

2B. Sepals much longer than broad.

1C. Petals white or greenish..... 2. *P. grandiflora*

2C. Petals pink to purple..... 3. *P. asarifolia*

2A. Style straight; stigma capitate, broader.

1B. Style included..... 4. *P. minor*

2B. Style exerted..... 5. *P. secunda*

1. *P. chlorantha* Swartz.

Greenish-flowered Wintergreen.

Scapes 1–3 dm. tall, 3- to 10-flowered; leaves obscurely crenulate or entire, orbicular or broadly oval, rounded at both ends or sometimes mucronate at the apex, 1–3 cm. long; sepals triangular-ovate, about 1.5 mm. long; petals greenish-white, about 6 mm. long; capsule about 7 mm. in diameter.

Woods, circumpolar, south to D. C., Ariz., and Calif. Fig. 786.

2. *P. grandiflora* Radius.

Large-flowered Wintergreen.

P. borealis Rydb.

P. gormanii Rydb.

P. occidentalis Rydb.

Scapes 8–20 cm. tall; leaves orbicular or oval with light-colored veins, 15–50 mm. long; flowers 5–10, 15–22 mm. wide; sepals usually pinkish, about 3 mm. long; petals whitish 6–9 mm. long; fruit about 8 mm. in diameter.

Circumpolar, high arctic to Kenai Penin. and Quebec. Fig. 787.

3. *P. asarifolia* Michx.

Liver-leaf Wintergreen.

P. uliginosa Torr.

Scapes 15–40 cm. tall; leaves oval, orbicular or reniform, sometimes broader than long, crenulate, shining, 2–7 cm. long; sepals acute or

acuminate, about 3 mm. long; petals pink to purplish, oval, about 7 mm. long; capsules about 6 mm. in diameter. The typical form has leaves somewhat cordate at the base, the more common var. *incarnata* (DC.) Fern. has leaves with rounded or slightly cuneate bases.

Woods, Siberia and Japan—Yukon—N. S.—Mass.—Mich.—S. Dak.—N. Mex.—Calif. Fig. 788.

4. *P. minor* L.

Lesser Wintergreen.

Erxlebania minor (L.) Rydb.

Scapes 5–20 cm. tall; leaves orbicular or oval, slightly crenulate, obtuse or mucronate at the apex, rounded at the base, 15–40 × 10–30 mm.; sepals triangular-ovate, about 1.5 mm. long; petals white or more usually pink, orbicular, 4–5 mm. long; style short, included; capsule about 5 mm. in diameter.

Woods, circumpolar, south to Aleutians, Conn., Colo., and Calif. Fig. 789.

5. *P. secunda* L.

One-sided Wintergreen.

Ramischia secunda (L.) Gercke.

Scapes usually several from a much-branched rootstock, 8–20 cm. tall; leaves elliptical, 15–35 mm. long, crenulate, acute or mucronate at the tip, rounded or narrowed at the base; flowers greenish-white in a one-sided raceme; pedicels short; calyx lobes triangular, obtuse, very short; petals oval, about 4 mm. long; capsule subglobose, about 4 mm. long. Var. *obtusata* Turcz. is a smaller growing form of central and northern Alaska.

Woods, circumpolar, south to N. J., N. Mex., and Calif. Fig. 790.

37. MONOTROPACEAE (Indian Pipe Family)

Saprophytes growing in humus or root parasites without chlorophyll; leaves reduced to scales; flowers perfect, usually drooping; calyx 2- to 6-parted; sepals erect, deciduous; petals distinct or partly united; stamens 6–12, anthers 2-celled or confluent 1-celled; ovary superior. 4- to 6-lobed, 1- to 6-celled; fruit a 1- to 6-celled loculicidal capsule with numerous seeds.

Flower solitary; stigma naked.....1. *Monotropa*
Flowers racemose; stigma hairy on the margin.....2. *Hypopitys*

1. MONOTROPA L.

Succulent white, yellowish or reddish plants; flower nodding, but the capsule erect; sepals 2–4; petals 5 or 6; stamens 10–12; capsule 5-celled, 5-valved; seed with the testa prolonged at both ends. (Greek, once and turned.)

M. uniflora L.

Indian Pipe.

Stems white or reddish, turning blackish in drying, 10–25 cm. tall; flowers 15–20 mm. long; capsule obtusely angled, 10–15 × 8–10 mm.

Rich woods, Hyder—Newf.—Fla.—Mex.—Calif., and in Japan—India. Fig. 791.

2. HYPOPITYS (Dill.) Adans.

Yellowish or reddish plants with sessile scales and the flowers in a nodding one-sided raceme which soon becomes erect; terminal flower 5-merous, the lateral ones 3- to 4-merous; petals saccate at the base; stamens 6-10; anthers horizontal; ovary 3- to 5-celled; styles short; stigmas funnel-form with ciliate margins. (Greek, under a fir tree.)

H. latisquama Rydb.

Pinesap.

Plant pinkish, slightly fragrant, pubescent above, 1-3 dm. tall; scales ovate, 10-15 mm. long; sepals spatulate or cuneate with acute tip, ciliate, 7-10 mm. long; petals obovate or cuneate, 10-15 mm. long, rounded and sinuate at the apex, ciliate and pubescent; capsule scaly, about 8 mm. long.

Southeast Alaska—Mont.—N. Mex.—B. C. Fig. 792.

38. ERICACEAE (Heath Family)

Ours all shrubs or subshrubs; leaves simple, often leathery and persistent; flowers perfect, usually gamopetalous; calyx of 4 or 5 sepals, usually partly united; corolla regular or nearly so; stamens as many or twice as many as the corolla lobes; anthers 2-celled, the sacs often prolonged into tubes; ovary 2- to 5-celled; fruit a capsule, berry or drupe.

1A. Fruit a septicidal capsule; corolla deciduous; anthers unappendaged. (RHODODENDREAE)

1B. Corolla of separate petals, capsule dehiscent from the base.

1C. Leaves wooly beneath..... 1. *Ledum*

2C. Leaves glabrous and shiny..... 2. *Cladothamnus*

2B. Corolla gamopetalous, capsule dehiscent from the top.

1C. Seed flat, winged.

1D. Leaves evergreen..... 3. *Rhododendron*

2D. Leaves deciduous..... 4. *Menziesia*

2C. Seed angled or rounded.

1D. Stamens 5; capsule 2- to 5-celled..... 5. *Loiseleuria*

2D. Stamens 10; capsule 5-celled.

1E. Corolla saucer-shaped..... 6. *Kalmia*

2E. Corolla ovoid..... 7. *Phyllodoce*

2A. Fruit a loculicidal capsule; anthers often awned. (ANDROMEDAE)

1B. Low heath-like shrubs with small thick imbricate leaves; corolla campanulate..... 8. *Cassiope*

2B. Shrubs; corolla urceolate or ovate-cylindric.

1C. Anther cells beaked but not awned..... 9. *Chamaedaphne*

2C. Anther cells awned..... 10. *Andromeda*

3A. Fruit a drupe or the capsule enclosed by the fleshy accrescent calyx.

1B. Fruit the fleshy calyx surrounding the ovary

(GAULTHERIAE)..... 11. *Gaultheria*

2B. Fruit a drupe with 4 or 5 nutlets. (ARBUTAE)..... 12. *Arctostaphylos*

1. LEDUM L.

Resinous, branching, evergreen shrubs; leaves alternate, coriaceous, thick, with revolute margins; flowers white, from terminal scaly buds; calyx small, persistent, 5-lobed; corolla of 5 separate spreading petals;

stamens 5-10, exerted; anthers small, opening by terminal pores; ovary 5-celled, stigma 5-lobed; capsule 5-valved. (Greek, from a plant now placed in a different family; *Cistus ledon*, the Rock Rose.)

Leaves linear; stamens about 10.....1. *L. decumbens*
 Leaves oblong, stamens 5-10.....2. *L. groenlandicum*

1. *L. decumbens* (Ait.) Lodd. Narrow-leaved Labrador Tea.
L. palustris decumbens (Ait.) Hult.

Similar to *L. groenlandicum* but much smaller and more decumbent, 1-5 dm. tall; leaves linear, 10-25 mm. long, 0.5-3 mm. wide; pedicels very pubescent.

Common in muskegs and alpine situations, east Asia—Greenl.—Newf.—Skagway—Aleutians. Fig. 793.

2. *L. groenlandicum* Oeder. Labrador Tea.
L. pacificum Small.

3-10 dm. tall; leaves oblong to linear-oblong, obtuse, strongly revolute, densely red-wooly beneath, green and rugose above, 15-50 × 3-10 mm.; flowers numerous; petals about 5 mm. long; stamens slender; pedicels 15-25 mm. long, recurved in fruit; capsule 4-6 mm. long.

Muskegs and woods, central Alaska—Greenl.—Mass.—Pa.—Wash. Fig. 794.

2. CLADOTHAMNUS Bong.

Erect or ascending shrub; leaves alternate, deciduous, entire; flowers one or two, terminal; sepals and petals each 5, distinct or nearly so; stamens 10 with filaments dilated at the bases; style curving; stigma capitate; ovary and capsule 5-celled. (Greek, branch and bush.)

- C. pyrolaeiflorus* Bong. Copper Bush.

6-12 dm. tall, the bark exfoliating; leaves ovate to oblanceolate, 15-40 mm. long, shining above, paler beneath, mucronulate; sepals linear, acute; petals coppery pink, oblong, 10-12 mm. long; capsule flattened, about 6 mm. in diameter.

Alpine and subalpine, southeast Alaska—Ore. Fig. 795.

3. RHODODENDRON L.

Ours evergreen shrubs or subshrubs; leaves alternate, entire, short-petioled; calyx 5-parted, often small; corolla from rotate to campanulate, the limb 5-lobed, often somewhat irregular; stamens usually 10; anthers opening by pores at the apex; ovary 5- to 10-celled; capsule separating into 5-10 valves, seed numerous. (Greek, rose and wood.)

Flowers 1-3.....1. *R. kamtschaticum*
 Flowers several, borne in umbels.....2. *R. lapponicum*

1. *R. kamtschaticum* Pall. Kamchatka Rhododendron.
Thororhodon kamtschaticum (Pall.) Small.

A subshrub a few centimeters tall; leaves spatulate to obovate, 15–35 mm. long, ciliate on the margins and on the veins beneath, cuneate at the base, rounded and mucronulate at the apex; flowers borne on the new growth; sepals ovate or elliptic, foliaceous and with ciliate margins, 12–15 mm. long; corolla rose-purple, 35–45 mm. across, the lobes ovate with finely ciliate margins; base of corolla densely pubescent. *Ssp. glandulosum* (Standl.) Hult. is a lower-growing form more or less glandular on the leaf margins and the corolla nonciliate.

An Asiatic species extending into western Alaska, the subspecies in Seward Peninsula and lower Yukon valley. Fig. 796.

2. *R. lapponicum* (L.) Wahl.
R. parvifolium Adams.

Lapland Rose Bay.

A low, depressed, prostrate shrub 5–25 cm. tall; leaves oval or elliptic, obtuse, entire, 6–16 mm. long, more or less revolute on the margins, the lower surface brownish in age, both surfaces covered with scales as also the peduncles and capsule; corolla pinkish-purple, 15–20 mm. broad; capsule ovoid, about 5 mm. high.

Alpine, in Alaska north of 63 degrees; circumpolar, south to New York. Fig. 797.

4. MENZIESIA Smith.

Erect branching shrubs; leaves deciduous, alternate, membranous; flowers 4-merous, in corymbs from terminal buds; calyx 4-lobed; corolla urceolate; stamens usually 8, included; anthers linear-sagittate, opening by terminal chinks; ovary 4-celled; stigma 4-lobed or toothed. (Archibald Menzies was a surgeon and naturalist.)

M. ferruginea Smith.

Rusty Menziesia.

An odorous shrub 15–30 dm. tall; leaves oblanceolate, mucronate, hirsute above, on the margins and on the veins beneath, 2–6 cm. long; calyx ciliate-margined; corolla coppery pink, 7–9 mm. long; capsule ovoid.

In woods, central Alaska—Wyo.—Ore. Fig. 798.

5. LOISELEURIA Desv.

A low, glabrous, depressed, caespitose, evergreen subshrub; leaves small, linear-oblong, coriaceous, entire, obtuse, petioled; calyx deeply 5-parted, the divisions ovate-lanceolate, reddish-purple, persistent; corolla campanulate, 5-lobed; stamens 5, opening by slits; ovary 2- or 3-celled; capsule 2- or 3-valved, the valves 2-cleft. (Loiseleur was a French botanist.)

L. procumbens (L.) Desv.

Alpine or Trailing Azalea.

A diffusely-branched subshrub sometimes forming mats up to 2 or 3 dm. in diameter but usually much smaller; leaves crowded, 3–7 mm. long, pale with a prominent ridge beneath; flowers pink or white, about

4 mm. long, in small terminal clusters; capsules 2-2.5 mm. in diameter.

Mostly alpine, circumpolar, south to New Hampshire and the 49th parallel. Fig. 799.

6. KALMIA L.

Glabrous, evergreen shrubs; leaves in ours opposite; coriaceous; flowers in terminal or axillary corymbs with deciduous bracts; sepals 5, coriaceous, persistent; corolla rotate, 10-keeled, 5-lobed; stamens 10; anthers at first enclosed in pouches of the corolla, awnless, opening by terminal pores; capsule 5-valved. (Peter Kalm was a pupil of Linnaeus.)

K. polifolia Wang.

Swamp Laurel.

K. microphylla (Hook.) Heller.

K. occidentalis Small.

A sparingly branched shrub 1-3 dm. tall; leaves 15-35 mm. long, dark green above, glaucous beneath, entire, revolute; sepals purplish, ovate, concave, about 3 mm. long; corolla rose, 12-18 mm. wide; capsules about 4 mm. thick and 5 mm. long.

Muskegs, southeast Alaska and Yukon—Newf.—Penn.—Mich.—Mont.—Calif. Fig. 800.

7. PHYLLODOCE Salisb.

Low, branching, evergreen shrubs; leaves narrow, coriaceous, crowded, linear, obtuse; flowers in terminal corymbs; sepals 5, persistent; stamens 10, included; anthers awnless, opening by pores; filaments glabrous; capsule 5-valved to the middle; seeds minute, with coriaceous testa. (Greek, a sea nymph.)

1A. Flowers blue.....1. *P. coerulea*

2A. Flowers pink to red.....2. *P. empetriformis*

3A. Flowers yellowish.

1B. Corolla glandular-puberulent.....3. *P. glanduliflora*

2B. Corolla glabrous.....4. *P. aleutica*

1. *P. coerulea* (L.) Babingt.

Blue Mountain Heather.

8-15 cm. tall with ascending branches; leaves 4-10 mm. long, less than 2 mm. wide, their margins scabrous or serrulate; calyx teeth lanceolate, acute; pedicels glandular, elongating in fruit; corolla ovoid, 7-8 mm. long, glabrous; capsules about 4 mm. in diameter. Hybridizes with *P. aleutica*.

Attu Island and east North America, Eurasia. Fig. 801.

2. *P. empetriformis* (Smith) D. Don.

Red or Purple Heather.

Plants up to 15 cm. tall, tufted or matted; leaves 6-15 mm. long, revolute; calyx lobes ovate; corolla campanulate, pink to red, 7-9 mm. long; capsules globular, about 3 mm. in diameter.

Southeast Alaska—Mack.—Alberta—Colo.—Calif. Fig. 802.

3. *P. glanduliflora* (Hook.) Cov. Yellow Heather.

Stems 1-3 dm. tall; leaves sessile, linear-oblong, serrulate, rugose, with a narrow furrow above and a light, minutely hairy line below, 6-10 mm. long; pedicels, calyx and corolla glandular-pubescent; sepals lanceolate, acute; corolla urceolate, about 8 mm. long.

South Alaska—Alta.—Wyo.—Ore. Fig. 803.

4. *P. aleutica* (Spreng.) A. Heller. Aleutian Heather.

Plants up to 20 cm. tall; leaves linear, 5-11 mm. long, obtuse, serrulate; calyx lobes linear to lanceolate; corolla globose-urceolate, 6-8 mm. long.

East Asia, Aleutians—Bering Sea region and Pr. William Id. Fig. 804.

8. CASSIOPE D. Don.

Low, branching, evergreen shrubs or subshrubs; leaves thick; flowers axillary or terminal, nodding on slender pedicels; sepals usually 5, thickened at the base; corolla campanulate, usually 5-lobed; stamens included; anthers attached near the apex, opening by large terminal pores and tipped by recurving awns; style thickened below; capsule 4- to 5-valved. (Cassiope of Greek mythology was mother of Andromeda.)

1A. Leaves spreading, flowers terminal.....1. *C. stelleriana*

2A. Leaves 4-ranked, appressed.

1B. Leaves furrowed on back.....2. *C. tetragona*

2B. Leaves not furrowed on back.

1C. Diameter of stem with appressed leaves 2.5 mm. or more. 3. *C. mertensiana*

2C. Diameter of stem with appressed leaves 1.5-2 mm.....4. *C. lycopodioides*

1. *C. stelleriana* (Pall.) DC. Alaska Heather.

Harrimanella stelleriana (Pall.) Cov.

Stems 5-20 cm. long; leaves very numerous, oblanceolate, 3-5 mm. long, flattish above, slightly keeled beneath; calyx lobes oval with yellowish margins, about 3 mm. long; corolla white, lobed about half way to the base, about 6 mm. long; capsule erect.

Alpine, east Asia and the Aleutians along the coast to Wash. Fig. 805.

2. *C. tetragona* (L.) D. Don. Four-angled Mountain Heather.

More or less decumbent at the base, the ascending branches 1-2 dm. tall; leaves very thick, ovate, 3-5 mm. long with a deep furrow on the back; peduncles 10-25 mm. long; sepals about 2.5 mm. long, acute; corolla white or pink, 5-6 mm. long; capsule much longer than the calyx; diameter of branches including leaves 4-5 mm.

Alpine, east Asia and the Aleutians along the coast to Wash. Fig. 806.

3. *C. mertensiana* (Bong.) D. Don. Mertens Mountain Heather.

Similar to *C. tetragona*; leaves ovate-lanceolate, 2.5-4 mm. long, concave above, round-keeled on the back; peduncles 8-15 mm. long; sepals

pinkish, ovate, acute, 2.5–3 mm. long; corolla white or pinkish, 6–8 mm. long; capsule a little longer than the calyx.

Alpine, southeastern Alaska—Alta.—Mont.—Calif. Fig. 807.

4. *C. lycopodioides* (Pall.) D. Don. Club-moss Mountain Heather.

Stems more or less prostrate, 5–20 cm. long; leaves very closely and evenly appressed, 2–3 mm. long; sepals ovate, obtuse, the margins hyaline, about 2 mm. long; corolla white, about 6 mm. long, the ovate lobes nearly as long as the tube; capsule a little longer than the calyx.

Rocky alpine, east Asia—Aleutians—southeast Alaska. Fig. 808.

9. CHAMAEDAPHNE Moench.

An erect branched shrub with rather slender terete branches; leaves alternate, coriaceous, evergreen; flowers in terminal, leafy racemes; calyx of 5 distinct sepals bracted at the base; corolla oblong-cylindric with 5 recurved teeth; stamens 10, included; anthers-sacs tapering upward into tubular beaks, not awned; ovary 5-celled; capsule 5-valved. (Greek, ground or low Daphne.)

C. calyculata (L.) Moench. Leather-leaf.

Andromeda calyculata L.

Cassandra calyculata (L.) D. Don.

6–12 dm. tall with pubescent twigs; leaves thick, rugose above and covered underneath with minute, roundish, scurfy scales which often occur on the upper surface also, the margins minutely wavy toward the tips, 12–40 mm. long; corolla about 6 mm. long; capsule about 4 mm. in diameter, a little longer than the calyx.

Swamps and wet woods, circumpolar, south to Ga.—Ill.—B. C. Fig. 809.

10. ANDROMEDA L.

A low, glabrous, evergreen shrub; leaves narrow, alternate, coriaceous, strongly revolute; flowers in terminal corymbs; sepals 5, persistent; corolla globose-urceolate with 5 recurved teeth; stamens 10, included; filaments bearded; anthers with ascending awns; ovary 5-celled; capsule subglobose, 5-valved; seed shining. (In mythology Andromeda was a daughter of Cassiope.)

A. polifolia L. Bog Rosemary.

1–4 dm. tall; leaves oblong to linear, dark green above, glaucous beneath, 2–4 cm. long, mucronulate; pedicels 10–20 mm. long; sepals triangular, acute, about 1 mm. long; corolla pink, about 6 mm. long.

Bogs, circumpolar, south to N. J.—Idaho—Wash. Fig. 810.

11. GAULTHERIA (Kalm) L.

Shrubs with hairy twigs; leaves alternate, coriaceous, evergreen; calyx 5-cleft, persistent; corolla urceolate or campanulate, 5-toothed or

lobed; stamens 10, included; filaments dilated above the base; anthers opening by terminal pores; capsule enclosed by the enlarged and fleshy calyx forming a berry-like fruit. (Named for Dr. Gaultier of Quebec.)

Racemes many-flowered.....1. *G. shallon*
 Racemes 1- to 6-flowered.....2. *G. miqueliana*

1. *G. shallon* Pursh.

Salal.

Partially decumbent or erect, stout, 2-12 dm. tall; leaves oval or ovate, serrate, mucronate, cordate at the base, 3-8 cm. long; flowers in glandular-pubescent bracted racemes; calyx with prominent, stiff, reddish-brown, glandular hairs; corolla ovoid, pubescent, 6-8 mm. long; filaments hairy; anthers with 4 awns; fruit purple.

Southeast Alaska—Calif. Fig. 811.

2. *G. miqueliana* Takeda.

Stems up to 35 cm. tall, procumbent at the base, the branches ascending; leaves short-petioled, oval to oblong-oval, 15-35 × 8-16 mm.; calyx lobes triangular, glandular-pubescent on the back, the apex ciliolate; corolla ovoid-urceolate, about 5 mm. long; anthers 4-aristate at the apex; fruit globose, 10 mm. long.

An east Asiatic species found on Kiska Island.

12. ARCTOSTAPHYLOS Adans.

Flowers in small, terminal, bracteolate racemes; calyx small, 4- to 5-parted; corolla urceolate with 4 or 5 recurved lobes; stamens included; anthers with 2 recurved awns on the back; ovary 4- to 10-celled; fruit a drupe with 1-8 more or less coherent nutlets. (Greek, bear and bunch of grapes.)

Stems long-trailing; leaves evergreen.....1. *A. uva-ursi*
 Stems short; leaves deciduous.....2. *A. alpina*

1. *A. uva-ursi* (L.) Spreng.

Bearberry. Kinnikinnick.

Depressed and spreading over ground and rocks, forming patches sometimes 1-2 m. in diameter; leaves spatulate, reticulate, the apex rounded, the base cuneate; corolla white, 4-5 mm. long; fruit red, globose, 6-10 mm. in diameter, usually containing 5 coalesced nutlets.

Circumpolar, south to Va.—Ill.—N. Mex.—Calif. Fig. 812.

2. *A. alpina* (L.) Spreng.

Alpine Bearberry.

Arctous alpina (L.) Niedzu.

Mairania alpina (L.) Desv.

A depressed, prostrate subshrub, 3-10 cm. tall; leaves spatulate or ovate, finely crenate, reticulate-veined, 15-30 mm. long; corolla white or pink; fruit bluish-black when ripe, 6-8 mm. in diameter. The typical form is usually alpine. In woods at lower elevations is variety *rubra* (Fern.) Rhed. & Wils. (*A. rubra* Fern.) (*Arctous erythrocarpa* Small.) which is somewhat larger-growing and has red fruit.

Circumpolar, south to Newf., N. Hamp. and B. C., the var. in Alaska—Man.—B. C. Fig. 813.

39. VACCINIACEAE (Blueberry Family)

Ours all shrubs or trailing vines; leaves alternate, often coriaceous, simple, sometimes evergreen; flowers small, perfect, white, pink, or red, clustered or solitary; calyx tube adherent to the ovary, 4- or 5-toothed, -lobed or -parted; corolla gamopetalous with 4 or 5 lobes, or in *Oxycoccus* of nearly distinct free petals; stamens twice as many as the corolla-lobes; ovary 4- to 10-celled; fruit a berry.

Petals united.....1. *Vaccinium*
 Petals distinct and reflexed.....2. *Oxycoccus*

1. VACCINIUM L.

Ours all branching shrubs; calyx lobes small; fruit a many-seeded berry with or without bloom. (Ancient Latin name for the blueberry.)

1A. Corolla open campanulate; leaves evergreen.....1. *V. vitis-idea*

2A. Corolla cylindric to urceolate; leaves deciduous.

1B. Tall shrubs, 5 dm. or more tall.

1C. Fruit red.....3. *V. parvifolium*

2C. Fruit blue or black.

1D. Leaves finely serrulate.

1E. Leaves firm, strongly reticulate.....7. *V. paludicola*

2E. Leaves thin, not reticulate.....6. *V. membranaceum*

2D. Leaf margins entire or nearly so.

1E. Corolla ovoid; early-flowering.....4. *V. ovalifolium*

2E. Corolla depressed urceolate, flowering later.....5. *V. alaskensis*

2B. Low shrubs, less than 5 dm. tall.

1C. Flowers arising from scaly buds on old wood.....2. *V. uliginosum*

2C. Flowers borne on current seasons growth.

1D. Twigs distinctly angled, usually more than

25 cm. tall.....7. *V. paludicola*

2D. Twigs not distinctly angled, usually less than

25 cm. tall.....8. *V. caespitosum*

1. *V. vitis-idea* L.

Mountain Cranberry. Lingon Berry.

Low evergreen subshrub 5-15 cm. tall with a more or less creeping stem; leaves thick, obovate, green and shining above, pale and spotted beneath, 5-15 mm. long, the margins slightly revolute; corolla 4-lobed, light rose, about 5 mm. long; berry bright red, acid, 6-8 mm. in diameter. Our form is smaller than the European and has been separated as subspecies *minus* Lodd.

Circumpolar, the ssp. south to Mass., Minn., and Wash. Fig. 814.

2. *V. uliginosum* L.

Bog Blueberry.

A much branched shrub 1-6 dm. tall; leaves obovate, thickish, entire, glaucescent and paler beneath, 1-2 cm. long; calyx lobes rounded; corolla light pink; berries blue-black with bloom, from oblate to cylindrical, 6-15 mm. in diameter. This is the common blueberry of interior Alaska

and used in large quantities. In southeast Alaska it is largely a bog or alpine dweller and not much used.

Circumpolar, south to Newf., Maine, N. Y., B. C. Fig. 815.

3. *V. parvifolium* Smith.

Red Huckleberry.

5-15 dm. tall with green, sharply-angled branches; leaves oblong or oval, obtuse or rounded at both ends, mucronulate, 1-3 cm. long, entire except on basal shoots on which they are often serrulate and evergreen; flowers solitary and axillary; fruit red, translucent, pleasantly acid, 7-10 mm. in diameter.

South Alaska—Idaho—Calif. Fig. 816.

4. *V. ovalifolium* Smith.

Early Blueberry.

5-15 dm. tall with slender twigs; leaves glabrous, entire, 15-50 mm. long, pale and glaucous beneath; flowers solitary, preceding the leaves; corolla light pink, 5-7 mm. long; fruit blue with bloom; globular or slightly oblate, 8-12 mm. in diameter.

This and the next species furnish most of the blueberries gathered in the Pacific coast region of Alaska. Japan—Aleutians—Oregon, and in eastern North America. Fig. 817.

5. *V. alaskensis* Howell.

Alaska Blueberry.

A shrub 6-18 dm. tall with stout reddish twigs; leaves oval, paler beneath, acute, entire or irregularly serrulate, 2-7 cm. long; flowers borne singly, appearing with the leaves; corolla depressed urceolate, green shaded red; berry variable, from depressed-globose to pyriform, reddish-black to blue-black, with or without bloom, 10-15 mm. in diameter.

Woods, Prince William Sound—Ore. Fig. 818.

6. *V. membranaceum* Dougl.

Thin-leaved Blueberry.

A widely spreading shrub with angled twigs, 3-12 dm. tall; leaves oval, thin, very finely serrate, only slightly paler beneath, 2-7 cm. long, mucronulate at the apex; corolla depressed-globose; fruit globose or slightly oblate, dark purple to black, 8-10 mm. in diameter.

Southeast Alaska—Mich.—Ore. Fig. 819.

7. *V. paludicola* Camp.

Swamp Blueberry.

Stems 15-60 cm. tall, the branches angled and puberulent; leaves elliptic-obovate, subcoriaceous, green and shining, the margins minutely glandular serrulate, $20-35 \times 10-15$ mm.; corolla ovoid-urceolate, pink, about 6 mm. long; berry with bloom, about 10 mm. in diameter.

Swampy places, southeast Alaska and B. C. Fig. 820.

8. *V. caespitosa* Michx.

Dwarf Blueberry.

Stems much branched, 6-25 cm. tall; leaves obovate, often cuneate

at the base, serrulate, the teeth mucronulate, somewhat rugose above and net-veined beneath, 1-3 cm. long; flowers pink; berry blue with bloom, 6-8 mm. in diameter, quite sweet. Resembles a low-growing, small-fruited *V. paludicola*.

Central Alaska—Labr.—Maine—N. Y.—Wis.—Colo.

2. OXYCOCCUS (Tourn.) Hill.

Delicate trailing or creeping vines; leaves small, alternate, nearly sessile, persistent; flowers solitary or few, pendulous, slender peduncled, red or pink; petals 4, narrow, recurved; stamens 8; anther-sacs prolonged into slender tubes with terminal pores; fruit a globose or ellipsoid, acid, red berry. (Greek, sour berry.)

O. microcarpus Turcz.

Swamp Cranberry.

O. oxycoccus and *O. intermedia* of reports from Alaska.

Stems very slender, creeping through the moss and rooting at the nodes, 1-4 dm. long; leaves thick and leathery, ovate with rounded bases and revolute margins, acute at the apex, whitish underneath, 4-8 mm. long; flowers 1-4, terminal; petals 4-6 mm. long, berry globose to ellipsoid, 6-10 mm. in diameter.

Circumpolar, south to Manitoba and Alberta. Fig. 821.

40. DIAPENSIACEAE (Diapensia Family)

Ours a low, tufted subshrub; leaves simple, alternate or basal, persistent; flowers perfect, axillary, regular; calyx 5-parted, persistent; corolla 5-lobed, 5-cleft, or 5-parted, deciduous; stamens 5, in ours inserted on the corolla tube and alternate with its lobes; ovary superior, 3-celled; style persistent; stigma 3-lobed; capsule 3-celled, 3-valved; seed minute.

DIAPENSIA L.

Glabrous densely tufted subshrubs; leaves thick and firm; flowers on erect peduncles, white or pink; calyx bracted at the base, the sepals oval, obtuse, firm; corolla campanulate, 5-lobed; stamens inserted in the sinuses of the corolla; seed reticulated. (Greek, by fives.)

D. lapponica L. ssp. *obovata* (F. Schmidt) Hult.

Diapensia.

Stems usually much branched forming dense cushion-like tufts; leaves crowded, spatulate, sessile, rounded at the apex, usually curved, entire, 4-10 mm. long; peduncles becoming 2-4 cm. long in fruit; corolla whitish; 7-8 mm. long.

Alpine-arctic, east Asia and Alaska, the typical *D. lapponica* in east North America and Eurasia. Fig. 822.

41. PRIMULACEAE (Primrose Family)

Annual or perennial herbs; leaves simple; flowers perfect, regular; sepals 4-9, partially united; corolla lobes 4-9; stamens as many as the corolla lobes and opposite them, partly adnate to the tube; ovary

1-celled with free central placenta; fruit a 1-celled capsule opening by 2-8 valves.

- 1A. Leaves all basal; flowers borne on scapes.
 - 1B. Corolla lobes reflexed.....1. *Dodecatheon*
 - 2B. Corolla lobes erect or spreading.
 - 1C. Corolla tube shorter than the calyx.....2. *Androsace*
 - 2C. Corolla tube equaling or exceeding the calyx.
 - 1D. Corolla open at the throat.....3. *Primula*
 - 2D. Corolla crested at the throat.....4. *Douglasia*
- 2A. Stems leafy.
 - 1B. Flowers in rather dense clusters.....5. *Lysimachia*
 - 2B. Flowers sessile in the axils.....6. *Glaux*
 - 3B. Flowers on long axillary peduncles.....7. *Trientalis*

1. DODECATHEON L.

Perennials with leaves in basal rosettes; flowers borne in an involucrate umbel on a naked scape; calyx 5-lobed, persistent, reflexed in flowering; corolla 4- or 5-parted, the lobes reflexed, the tube short; stamens 5, their filaments united, their anthers long and attached by their bases; ovary superior; style filiform; stigma capitate; ovules numerous. The various species of this genus are known as Shooting Stars or as Bird Bills. (Greek, twelve gods.)

- 1A. Anthers with a distinct filament tube.
 - 1B. Filament tube one-half as long as the anther or longer.....1. *D. pauciflorum*
 - 2B. Filament tube less than one-half as long as the anther...2. *D. macrocarpum*
- 2A. Filament tube very short or none.
 - 1B. Leaves broad with rounded or truncate base.....3. *D. frigidum*
 - 2B. Leaves gradually narrowed into a bordered petiole.....4. *D. viviparum*

1. *D. pauciflorum* (Durand) Greene.

Leaves glabrous, 3-10 cm. long; blades oblanceolate, entire; scapes 1- to 10-flowered; corolla purple; anthers 4-5 mm. long. This and the following may be races of the same species. The form mostly reported under this name is in reality the next.

Yukon—Gt. Slave L.—Sask.—Nebr.—Utah.

2. *D. macrocarpum* (Gray) Knuth.

D. superbum Pennell & Stair.

Rootstock usually short; leaves variable, oblanceolate, spatulate-oblong or ovate, up to 25 cm. long including the petiole, entire or sinuate-dentate; scapes up to 45 cm. tall in fruit, 3- to many-flowered, glabrous or slightly glandular in the inflorescence; corolla pale at the base, the violet or rose-purple lobes 10-18 mm. long; filament-tube yellow; capsule cylindric, 12-17 mm. long. The form with wide, ovate leaves has been described as var. *alaskanum* Hult.

Kodiak Isl.—Tanacross—Wash. Fig. 825.

3. *D. frigidum* C. & S.

Leaves ovate, obtuse, the margins usually wavy, 2-5 cm. long on petioles up to 7 cm. long; scapes 10-35 cm. tall, 1- to 7-flowered, glabrous below, glandular in the inflorescence; corolla lobes 5, 10-18 mm. long,

bluish or rose-purple; filaments 1 mm. or less long; anthers acute, 4-6 mm. long, purple; capsule 1 cm. or less long.

East Siberia—arctic Alaska—lower Mackenzie R.—northeast B. C. Fig. 823.

4. *D. viviparum* Greene.

D. integrifolium Michx. *pro parte*.

Rootstock stout; leaves oblanceolate, thick, up to 25 cm. long including petiole, occasionally denticulate; scapes up to 6 dm. long in fruit, few-flowered, glandular in the inflorescence; corolla lobes 4, up to 25 mm. long, purplish with a yellow ring around the base and purple at the base of the stamens; anthers purple, almost sessile, 6-10 mm. long.

Prince William Sound to Ore. Fig. 824.

2. ANDROSACE (Tourn.) L.

Low herbs with a dense basal tuft of leaves; flowers small, borne singly or in umbels on a scape; calyx 5-lobed or 5-parted; corolla salver- or funnel-form; the tube shorter than the calyx, the limb 5-lobed; stamens 5, included; style very short; stigma capitate; capsule 5-valved, 2- to many-seeded. (Greek, man's shield, from the shape of the leaf of some species.)

1A. Plant low, cushion-like..... 4. *A. ochotensis*

2A. Plant with rosulate basal leaves.

1B. Stemmed, caespitose perennial..... 1. *A. chamaejasme*
lehmanniana

2B. Plants acaulescent.

1C. Umbels several- to many-flowered..... 2. *A. septentrionalis*

2C. Umbels 1- or 2-flowered..... 3. *A. alaskana*

1. *A. chamaejasme* Host. ssp. *lehmanniana* (Spreng.) Hult.

A. carinata Torr.

Stems branched with the leaves in rosulate clusters at the ends of the branches; leaves oblanceolate, 4-10 mm. long; scapes usually less than 10 cm. tall; bracts narrow, acute; calyx about 2.5 mm. long, its lobes oval or oblong, obtuse; corolla cream-colored with yellow eye, the limb 8-10 mm. across. Var. *andersonii* Hult. has bracts more or less saccate at the base.

Eurasia—Victoria Isl.—Mackenzie delta—Kodiak—Aleutians. Fig. 826.

2. *A. septentrionalis* L.

A winter annual with a cushion of leaves at the base; leaves oblanceolate or oblong, acute, somewhat pubescent, denticulate or entire, 4-40 mm. long; scapes nearly glabrous, 6-40 cm. tall; bracts subulate, calyx about 3 mm. long, its lobes triangular with a rib to the base of the calyx; corolla white, small, slightly exceeding the calyx.

Eurasia—Victoria Isl.—Ellesmereland—N. Mex.—Calif. Fig. 827.

3. *A. alaskana* Cov. & Standl.

Leaves in a dense rosette at the top of a perennial caudex, ciliate on the margins and usually more or less pubescent on upper surface, usually 3-toothed at the apex, up to 25 mm. long; scapes several to many, 1- or 2-flowered, pubescent with simple and forked hairs when young, glabrate in age, up to 14 cm. long; flowers sessile with one lanceolate bract at the base of each flower; calyx about 5 mm. long; corolla slightly exceeding the calyx; seed dark brown, angular, 2-2.5 mm. long.

Alpine, Seward and Shumagin Islands. Fig. 828.

4. *A. ochotensis* Willd.

Cushions 1-3 cm. high; leaves 4-8 × 1-2 mm., obtuse, ciliate on the margins and more or less hirsute on the upper surface; peduncles 4-15 mm. long; calyx in fruit 2-2.5 mm. long, the teeth lanceolate; corolla rose-purple, its tube as long as or longer than the calyx.

East Siberia—Cape Lisburne—St. Matthew Isl. Fig. 829.

3. PRIMULA L.

Perennials with leaves in a basal rosette; flowers borne in an umbel at the top of a scape; calyx persistent, 5-toothed, usually angled; corolla funnel-form or salver-form, the tube equaling or exceeding the calyx; stamens 5, inserted on the tube or throat of the corolla; capsule 1-celled, 5-valved at the summit, many-seeded. (Latin, first, from the early blooming habits of some species.)

1A. Lobes of corolla entire.

1B. Leafless sheaths at base lacking..... 9. *P. nivalis*

2B. Leafless sheaths at base present..... 10. *P. tschuktschorum*

2A. Lobes of corolla emarginate or obcordate.

1B. Lobes of corolla very deeply cordate..... 1. *P. cuneifolia*

2B. Lobes of corolla less deeply cleft.

1C. Bracts of the involucre oblong with saccate auricles

at the base..... 8. *P. sibirica*

2C. Bracts of the involucre tapering to a point.

1D. Flowers small, leaves mostly entire..... 4. *P. egalikensis*

2D. Flowers larger, leaves mostly toothed.

1E. Scapes usually less than 1 dm. tall.

1F. Flowers pale, the limb usually less than

10 mm. across..... 6. *P. parvifolia*

2F. Flowers lilac or rose-purple.

1G. Limb of corolla 12-20 mm. across..... 5. *P. borealis*

2G. Limb of corolla smaller..... 7. *P. mistassinica*

2E. Plants usually more than 1 dm. tall.

1F. Leaves copiously farinose beneath..... 3. *P. incana*

2F. Leaves green beneath or only slightly farinose.

1G. Limb of corolla 5-8 mm. broad..... 2. *P. stricta*

2G. Limb of corolla 12-20 mm. broad..... 5. *P. borealis*

1. *P. cuneifolia* Ledeb.

Wedge-leaved Primrose.

Leaf blades spatulate to oblanceolate, cuneate at the base, rounded and toothed at the apex, 10-25 mm. long; scapes elongating in fruit,

25 mm. to 25 cm. tall, 1- to 5-flowered; calyx 2-4 mm. long, its teeth lanceolate; corolla pink to purplish, the limb 12-25 mm. across, the lobes deeply cleft. The ssp. *saxifragaefolia* (Lehm.) Hult. is the smaller, more common form.

Typical form is Asiatic, extending into the western Aleutians and Seward Penin., the ssp., from the Aleutians to southeast Alaska. Fig. 830.

2. *P. stricta* Hornem.

Leaves green or sparingly farinose beneath, oblanceolate to narrowly ovate, 5-40 \times 2-15 mm.; scapes 2-30 cm. tall, rather stout; bracts lance-subulate, usually somewhat saccate or gibbous at the base, 3-8 mm. long; umbel 2- to 8-flowered; calyx urceolate-campanulate, 4-6 mm. long at maturity, the lobes one-half as long as the tube; corolla lilac or violet, the lobes shallowly notched; capsule slightly longer than the calyx.

Of scattered circumpolar distribution, south to Que., Ont., Alta.

3. *P. incana* Jones.

Leaves farinose beneath, elliptic, oblong-ovate or spatulate, 15-80 \times 5-20 mm., shallowly denticulate; scapes 5-45 cm. tall, 2- to 14-flowered; bracts lanceolate to linear-oblong, flat, broadly gibbous at the base, 5-10 mm. long, usually equaling or exceeding the flowering pedicels; fruiting pedicels up to 25 mm. long; calyx farinose, the lobes shorter than the tube; corolla lilac, the limb 6-10 mm. broad; capsule ellipsoid, only slightly exceeding the calyx.

Central Alaska—Mack.—Colo.—Utah.

4. *P. egalikensis* Wormskj.

Greenland Primrose.

Leaves oval or lance-ovate, narrowed into winged petioles, the whole 6-20 mm. long, the margins entire or wavy; scapes slender, 5-23 cm. tall; umbel 1- to 9-flowered; bracts lanceolate, acuminate, dilated and somewhat saccate at the base; calyx 3-6 mm. long, the teeth short and acute; corolla tube yellow, the limb white, 4-8 mm. broad, the lobes cleft one-third to one-half their length; capsules slender, more than twice as long as the calyx.

West Alaska—Greenl.—Newf.—Que.—Alta.—B. C.

5. *P. borealis* Duby.

Northern Primrose.

Leaves cuneate-obovate to rhombic-spatulate, 6-45 mm. long including the margined petiole, more or less dentate above; scapes usually 5-10 cm. tall, sometimes taller; 1- to 10-flowered; bracts lance-subulate, dilated and often slightly saccate at the base; calyx 5-6 mm. long in fruit, the lobes nearly equaling the tube; capsule cylindric, slightly exceeding the calyx. Var. *ajanensis* (Busch) Hult. is usually somewhat smaller and is farinose on the lower surface of the leaves and in the inflorescence.

Asia—west Alaska—Banks Land. Fig. 831.

6. *P. parvifolia* Duby.

Small-leaved Primrose.

Leaves cuneate-obovate, spatulate or rhombic, denticulate, the lower scarcely petioled; scapes 4–10 cm. tall, rarely taller, 2- to 9-flowered; bracts lance- or linear-subulate, 2–5 mm. long, dilated and thickened but not saccate at the base; calyx 3–5 mm. long, the lobes about equaling the tube. Closely related to the preceding.

Asia, the Bering Sea and Seward Peninsula region.

7. *P. mistassinica* Michx.

Lake Mistassini Primrose.

Variable, leaves oblanceolate, spatulate, or cuneate-obovate, 5–70 × 2–6 mm., many of them dentate; scapes 3–21 cm. tall, 1- to 10-flowered; bracts linear-subulate, usually not saccate at the base, 2–6 mm. long; pedicels filiform, much exceeding the bracts; calyx 3–6 mm. long, the lobes equaling the tube; corolla tube yellow, the limb pink to bluish purple, 8–20 mm. broad; capsule subcylindric, 2–3 mm. in diameter, one and one-half times as long as the calyx.

East Alaska and Yukon—Labr.—Newf.—Maine—Mich.—Wis.—Minn.—B. C.

8. *P. sibirica* Jacq.

Siberian Primrose.

Leaves oval or elliptic, the blade 6–25 mm. long, the petioles often longer than the blade, the margins entire or minutely denticulate; scape slender, 5–20 cm. tall, 1- to 4-flowered; bracts oblong or obovate, 4–11 mm. long; calyx at maturity 5–6 mm. long, the tube twice as long as the oblong-ovate lobes; corolla lilac, the limb 10–18 mm. broad; capsule narrow, usually twice as long as the calyx.

Arctic Eurasia, Alaska and Yukon. Fig. 832.

9. *P. nivalis* Pall.

Snow Primrose.

Leaves elliptic to oblanceolate, up to 12 cm. or more long including the margined petiole, evenly serrate, farinose below; scapes stout, 1–2 dm. tall, 2- to 10-flowered; pedicels up to 4 cm. long in fruit; corolla lilac-purple; capsule 12–15 mm. long.

An east Asia species found around Cape Prince of Wales.

10. *P. tschuktschorum* Kjellm.

Chukch Primrose.

P. eximia Greene and *P. macounii* Greene.

Rootstock thick and short; leaves oblanceolate to ovate, sometimes quite narrow, the margins entire to crenate-dentate or serrate, 3–9 cm. long; scapes stout, 4–24 cm. tall, farinose in the inflorescence, few- to many-flowered; calyx 5–8 mm. long, the lobes about twice as long as the tube; corolla violet with lavender eye, the limb spreading, 12–20 mm. broad; capsule up to 20 mm. long.

East Asia and west Alaska. Fig. 833.

4. DOUGLASIA Lindl.

Low, perennial, cushion plants, suffrutescent at the base; leaves linear, imbricated, persistent, the dried ones covering the branches; flowers in our species solitary; calyx 5-angled, lobed to about the middle; corolla pink or violet; ovary 1-celled, usually 2- or 3-seeded; seeds brown, pitted. (David Douglas of Scotland made botanical explorations in northwest America.)

Leaves glabrous with ciliate margins.....1. *D. arctica*
 Leaves stellate pubescent.....2. *D. gormanii*

1. *D. arctica* Hook.

2-5 cm. tall; leaves closely imbricated; peduncles stellate-canescant; leaves narrowly oblanceolate, 4-8 × 1-2 mm., obtuse, thin, entire; calyx campanulate-turbinate, the lobes lanceolate, mucronate, 2 mm. long; corolla rose-pink, the tube 5-6 mm. long, the lobes cuneate, 3 mm. long, erose.

Arctic coast of Yukon to the Mackenzie R.

2. *D. gormanii* Const.

Leaves appressed, pubescent with simple and forked hairs, 4-10 × 1-2 mm., withering persistent and thickly investing the branches; peduncles stellate-pubescent, from very short to 3 cm. long in fruit; corolla rose-pink.

Central Alaska—Yukon. Fig. 834.

5. LYSIMACHIA (Tourn.) L.

Ours an erect, perennial, leafy marsh plant; leaves opposite, entire, rather narrow, the lower ones reduced; flowers yellow, in peduncled axillary spikes; sepals linear, 5-7; corolla deeply 5- to 7-parted with narrow lobes; stamens 5-7, exerted, alternating with small sterile stamens. (Greek, release and strife.)

L. thyrsiflora L.

Tufted Loosetrife.

Naumburgia thyrsiflora (L.) Duby.

Stem simple, 3-7 dm. tall; leaves sessile, linear to lanceolate, 5-10 cm. × 8-24 mm., acute, spotted, the lower ones reduced to scales; spike head-like, on peduncles 1-3 cm. long; pedicels short; calyx about 3 mm. long, spotted; corolla about 7 mm. long, the divisions linear and spotted near the apex.

Circumpolar, south to Penn. and Colo. Fig. 835.

6. GLAUX (Tourn.) L.

A low succulent perennial; leaves opposite, entire; flowers small, axillary, white or pinkish; corolla none; calyx campanulate and fleshy, colored like a corolla; stamens 5, inserted at the base of the calyx; capsule 5-valved at the summit; seeds few. (Greek, sea green.)

G. maritima L.

Sea Milkwort.

Stems very leafy, usually simple but often branched, 5-25 cm. tall;

leaves sessile, oval to linear oblong, 5–20 mm. long; calyx 3–4 mm. long, the lobes oval.

Sea beaches and salt marshes, circumpolar, south to N. J. and Calif. Fig. 836.

7. TRIENTALIS L.

Low perennials with tuberous rootstocks; stems simple with one to several small leaves along the stem and a cluster of larger leaves at the top; flowers few, often solitary, borne on slender peduncles from the axils of the upper leaves; corolla rotate, white or pinkish, parted to near the base; capsule 5-valved, few-seeded. (Latin, one third of a foot, referring to the height of some of the plants.)

T. europea L.

Star Flower.

Stems usually 1 dm. or less tall but may reach 2 dm.; leaves obovate or oblanceolate, cuneate at the base, 1–8 cm. long; flowers 1–3; sepals usually 7, narrow; corolla 12–18 mm. broad, 5- to 7-lobed; stamens mostly 7, arising from a ring at the base of the corolla; seed covered by a fine white network. The typical form occurs in the interior but most of the collections from our area are of the ssp. *arctica* (Fisch.) Hult.

East Asia—Athabasca region—B. C.—Aleutians. Fig. 837.

42. PLUMBAGINACEAE (Plumbago Family)

Ours a perennial herb; leaves basal and tufted; flowers small, perfect, regular; calyx tubular or funnelform, 5-toothed, plaited at the sinuses; stamens 5, opposite the corolla segments; anthers 2-celled; ovule solitary; fruit a utricle or achene enclosed by the calyx.

ARMERIA Willd.

Tufted fleshy herb; leaves narrow, in dense tufts; flowers in dense heads on naked scapes, subtended by bracts, the outer ones forming a sort of involucre, the lower ones reflexed and more or less united into a sheath. (An old Latin name.)

A. maritima (Mill.) Willd.

Sea Pink.

A. vulgaris arctica (Wallr.) Hult.

Statice armeria L.

Scapes 1–4 dm. tall; heads densely glomerate, leaves narrowly linear; bracts wide with rounded apex, the inner scarious; calyx scarious with dark, thickened base and ribs, pubescent at the base and on the ribs; corolla pink, purple, or white. Occurs in two forms. Var. *sibirica* (Turcz.) Lawr. Outer bracts one-half as long as the inner or less; leaves 6 cm. or less long. Var. *purpurea* (Mert. & Koch) Lawr. Outer bracts more than half as long as the inner; leaves flat, recurved or slightly contorted and canaliculate, 3–18 cm. long.

Circumpolar, var. *sibirica* arctic coast; var. *purpurea* Kotzebue and Aleutians—southeast Alaska. Fig. 838.

PLATE XXXI

Scale in millimeters.

FIG.

- 731. *Geranium erianthum* DC. Sepal, petal and leaf.
- 732. *Geranium sanguineum* L. Sepal and leaf.
- 733. *Geranium bicknellii* Britt. Fruit and leaf.
- 734. *Linum perenne lewisii* (Pursh) Hult. Leaf and fruit.
- 735. *Impatiens noli-tangere* L. Flower, leaf and fruit.
- 736. *Callitriche verne* L. Fruit, emersed and immersed leaves.
- 737. *Empetrum nigrum* L. pistillate and staminate flowers and leaf.
- 738. *Acer glabrum* var. *douglasii* (Hook.) Dipp. Samara and leaf.
- 739. *Viola glabella* Nutt. Flower, stipule and leaf.
- 740. *Viola biflora* L. Flower, stipule and leaf.
- 741. *Viola renifolia* var. *brainardi* (Greene) Fern. Fruit, stipule and leaf.
- 742. *Viola epipsila repens* (Turcz.) W. Bckr. Flower, stipules and leaf.
- 743. *Viola selkirkii* Pursh. Flower and leaf.
- 744. *Viola langsdorffii* Fisch. Flower, stipule and leaf.
- 745. *Viola adunca* Smith. Flower, leaf and stipule.
- 746. *Elaeagnus commutata* Bernh. Leaf, flower, fruit and stone.
- 747. *Shepherdia canadensis* (L.) Nutt. Fruit, leaf and stone.
- 748. *Circaea alpina* L. Flower, fruit and leaf.
- 749. *Epilobium angustifolium* L. Leaves and flower.
- 750. *Epilobium latifolium* L. Leaf and flower.

PLATE XXXI



PLATE XXXII

Scale in millimeters.

FIG.

751. *Epilobium luteum* Pursh. Leaf and flower.
752. *Epilobium davuricum* Fisch. Leaves and flower.
753. *Epilobium anagallidifolium* Lam. Leaf and seeds.
754. *Epilobium leptocarpum* Hausskn. Leaf and flower.
755. *Epilobium palustre* L. Leaves and end of stolon.
756. *Epilobium adenocaulon* Hausskn. Leaf and flower.
757. *Epilobium glandulosum* Lehm. Leaf and flower.
758. *Epilobium behringianum* Hausskn. Leaf and flower.
759. *Epilobium hornemannii* Rehb. Leaf and flower.
760. *Hippuris montana* Ledeb. Whorl of leaves, fruit and anther.
761. *Hippuris vulgaris* L. Whorl of leaves, flower and fruit.
762. *Hippuris tetraphylla* L.f. Whorl of leaves and fruit.
763. *Myriophyllum spicatum* L. Leaves and fruit.
764. *Oplopanax horridus* (Sm.) Miq. Half of leaf, flower and fruit.
765. *Osmorrhiza obtusa* (Coul. & Rose) Fern. Fruit.
766. *Osmorrhiza purpurea* (Coul. & Rose) Suksd. Fruit.
767. *Osmorrhiza chilense* Hook. & Arn. Fruit.
768. *Bupleurum americanum* (Coul. & Rose.) Stem leaf, section of carpel and fruit.
769. *Conioselinum benthami* (Wats.) Fern. Part of leaf, fruit and section of carpel.
770. *Conioselinum cnidifolium* (Turcz.) Pors. Part of leaf, fruit and section of carpel.
771. *Heracleum lanatum* Michx. Leaflet, fruit and section of carpel.

PLATE XXXII



PLATE XXXIII

Scale in millimeters.

Fig.

- 772. *Angelica lucida* L. Fruit, part of leaf and section of carpel.
- 773. *Angelica genuflexa* Nutt. Fruit, part of leaf, section of carpel.
- 774. *Ligusticum mutellinoides alpinum* (Ledeb.) Thellung. Fruit, leaf and section of carpel.
- 775. *Ligusticum hultenii* Fern. Fruit, part of leaf, section of carpel.
- 776. *Oenanthe sarmentosa* Presl. Part of leaf, fruit, section of carpel.
- 777. *Cicuta maculata* L. Leaflet, fruit and section of carpel.
- 778. *Cicuta douglasii* (DC.) Coult. & Rose. Leaflet, fruit and section of carpel.
- 779. *Cicuta mackenzieana* Raup. Leaflets, fruit and section of carpel.
- 780. *Sium suave* Walt. Leaflet, fruit and section of carpel.
- 781. *Cornus canadensis* L. Fruiting plant and flower cluster.
- 782. *Cornus suecica* L. Fruiting plant and single flower.
- 783. *Cornus stolonifera* Leaf, flower, and stone.
- 784. *Chamaphila umbellata* (L.) Pursh. Leaf, flower, and stamen.
- 785. *Moneses uniflora* (L.) Gray. Leaf, flower, fruit, and stamen.
- 786. *Pyrola chlorantha* Swartz. Leaf, fruit, and stamen.
- 787. *Pyrola grandiflora* Radius. Leaf, fruit, and stamen.
- 788. *Pyrola asarifolia incarnata* (DC.) Fern. Leaf, fruit, and stamen.
- 789. *Pyrola minor* L. Leaf, fruit, and stamen.

PLATE XXXIII



PLATE XXXIV

Scale in millimeters.

FIG.

790. *Pyrola secunda* L. Leaf, fruit, and anther.
791. *Monotropa uniflora* L. Flowering plant.
792. *Hypopitys latisquama* Rydb. Flower and fruit.
793. *Ledum decumbens* (Ait.) Lodd. Under surface of leaf, stamen, and fruit.
794. *Ledum groenlandicum* Oeder. Under surface of leaf, stamen, and fruit.
795. *Cladothamnus pyrolaeiflorus* Bong. Leaf, flower, and fruit.
796. *Rhododendron kamtschaticum* Pall. Flower and leaf.
797. *Rhododendron lapponicum* L. Flower, leaf, and fruit.
798. *Menziesia ferruginea* Smith. Leaf, flower, and fruit.
799. *Loiselevria procumbens* (L.) Desv. Flower, leaf, and fruit.
800. *Kalmia polifolia* Wang. Flower, leaf, and fruit.
801. *Phyllodoce coerulea* (L.) Bab. Flower and leaf.
802. *Phyllodoce empetriformis* (Smith) D. Don. Flower and leaf.
803. *Phyllodoce glanduliflora* (Hook.) Cov. Flower and leaves.
804. *Phyllodoce aleutica* (Spreng.) Hill. Flower, pistil, and stamen.
805. *Cassiope stelleriana* (Pall.) DC. Flower, fruit, and leaf.
806. *Cassiope tetragona* (L.) D. Don. Part of stem with flower, back of leaf, and fruit.
807. *Cassiope mertensiana* (Bong.) D. Don. Flower and leaf.
808. *Cassiope lycopodioides* (Pall.) D. Don. Part of stem with flower, leaf, and fruit.
809. *Chamaedaphne calyculata* (L.) Moench. Flower, leaf, and fruit.
810. *Andromeda polifolia* L. Leaf, flower, and fruit.
811. *Gaultheria shallon* Pursh. Flower and leaf.
812. *Arctostaphylos uva-ursi* (L.) Spreng. Flower, leaf, and stamen.
813. *Arctostaphylos alpina* (L.) Spreng. Leaf, anther, and flower.
814. *Vaccinium vitis-idea* L. Flower, leaf, and stamen.

PLATE XXXIV



PLATE XXXV

Scale in millimeters.

FIG.

- 815. *Vaccinium uliginosum* L. Flower, leaf, and stamen.
- 816. *Vaccinium parvifolium* L. Flower, leaf, and anther.
- 817. *Vaccinium ovalifolium* Smith. Flower, leaf, and stamen.
- 818. *Vaccinium alaskensis* Howell. Flower, leaf, and anther.
- 819. *Vaccinium membranaceum* Dougl. Flower and leaf.
- 820. *Vaccinium paludicola* Camp. Flower, leaf, and stamen.
- 821. *Oxycoccus microcarpus* Turcz. Flower, stamen, and leaves.
- 822. *Diapensia lapponica obovata* (Fr.Schm.) Hult. Tip of stem with flower.
- 823. *Dodecatheon frigidum* C. & S. Flower, leaf, and dehiscent capsule.
- 824. *Dodecatheon viviparum* Greene. Flower, leaf, and capsule.
- 825. *Dodecatheon macrocarpum* (Gray) Kunth. Flower and capsule.
- 826. *Androsace chamaejasme lehmanniana* (Spreng.) Hult. Limb of corolla, leaf and calyx.
- 827. *Androsace septentrionalis* L. Leaves and flower.
- 828. *Androsace alaskana* Cov. & Standl. Leaf and flower.
- 829. *Androsace ochotensis* Willd. Fruit and base of stem.
- 830. *Primula cuneifolia saxifragifolia* (Lehm.) Hult. Flower, leaf, and dehiscent capsule.
- 831. *Primula borealis* Duby. Limb of corolla, leaf, and capsule.
- 832. *Primula sibirica* Jacq. Limb of corolla, leaf, and capsule.
- 833. *Primula tschuktschorum* Kjellm. Limb of corolla, leaf, and capsule.
- 834. *Douglasia gormanii* Const. Dehiscent capsule and top of stem.
- 835. *Lysimachia thrysiflora* L. Flower and leaf.
- 836. *Glauz maritima*. Flower, leaf, and capsule.
- 837. *Trientalis europea arctica* (Fisch.) Hult. Flower and leaf.
- 838. *Armeria maritima* (Mill.) Willd. Leaf and calyx.

PLATE XXXV



REPORT ON THIRTY-FIVE DRUGS AND THREE PLANT MATERIALS TESTED AGAINST *PLASMODIUM LOPHURAE* IN THE WHITE PEKIN DUCK

ELERY R. BECKER

Department of Zoology and Entomology, Iowa State College

Received July 19, 1948

A research unit for testing the antimalarial activity of drugs in blood-induced *Plasmodium lophurae* infection in ducks was established at Iowa State College as the result of a research grant.¹ All of the drugs tested were obtained from the Antimalarial Drug Repository in the Division of Tropical Diseases, National Institute of Health. Data sheets covering the identity, chemical and physical properties, and toxicity of the drugs accompanied the shipments. If a drug had been tested previously in avian malaria the report of such testing appeared on the data sheet, also. The cooperation and counsel of Dr. G. Robert Coatney and Mr. William H. Longenecker of the National Institute of Health facilitated the work in many respects, and is herewith acknowledged.

The use of avian malaria in chemotherapy to 1942 has been treated historically by Bishop (1942). The various testing procedures employed in this country for screening antimalarial drugs in blood-induced avian malarias are outlined in detail in Volume I of *A Survey of Antimalarial Drugs 1944-1945* edited by Wiselogle (1946). These procedures differ in respect to species of malaria used, host employed, regimen of the drug, and certain other details, but in all of them the criterion of antimalarial activity is significant lowering of the parasitemia (either parasitized cells or number of parasites) in the treated birds on the day when the infection is at its peak in the untreated controls. The relative activity of such drugs as are effective is expressed in a quotient (the drug equivalent) whose denominator is the amount of the drug under assay that produces a significant reduction in parasitized cells (or parasites), and whose numerator is the amount of the drug standard (quinine, atabrin, chloroquine, etc.) that produces a comparable reduction of parasitemia. In case the reference drug is quinine the quotient is spoken of as the quinine equivalent, or Q.

As others (Marshall, 1946; Davey, 1946) have pointed out, the above outlined general procedure is a significant departure from Roehl's (1926), whose criterion of antimalarial activity was a significant delay

¹This investigation was supported (in part) by a research grant from the Division of Research Grants and Fellowships of the National Institute of Health, U. S. Public Health Service. In addition, gratitude is expressed to Dr. E. K. Marshall, Jr., Johns Hopkins University Medical School, for transferring certain valuable laboratory equipment to our unit.

in the time required for the appearance of *Plasmodium relictum* in the blood of canaries following intramuscular injection of the parasite and administration of the drug under assay for about 6 days. His quantitative evaluation of antimalarial activity was expressed as a chemotherapeutic index, which in this particular case was the ratio of the maximum dose of a drug tolerated by the canary to the minimum dose effective in delaying the parasitemia. The test adopted in this laboratory is of the same general type as those used elsewhere in this country, and has been designated "Test W-1" in National Institute of Health Malaria Report 52. Marshall, Litchfield and White's (1942) was similar to ours in certain respects, but they fed the drug in the diet at known concentrations and computed dosage at the end of the experiment on the basis of the probable weight of food consumed and daily weights of the ducks.

The host is the White Pekin duck. The ducklings arrive from the hatchery on either the first or second day after hatching, and are fed a commercial chick starter. They are started on the tests when ten to sixteen (usually twelve) days old. The plasmodium (*Plasmodium lophurae*) is maintained by intravenous passage at five- or six-day intervals through left-over ducklings that vary in age from two to six weeks. Passage and test inoculations are made in either the leg or right jugular vein with 0.5 cc. of blood diluted with heparanized saline. Approximately 2×10^8 parasitized red blood cells are injected into each bird.

The first administration of the test drug is made immediately after inoculation. Treatment is twice daily (b.i.d.), at 8:30 A.M. and 4:30 P.M., and extends over six consecutive days. The drug is dissolved in distilled water, or if insoluble, as is usually the case, it is ground to a very fine powder in a mortar and suspended in 12 per cent gum acacia in water. The drug is introduced into the crop through a soft rubber catheter attached to a Luer syringe. Every duckling is weighed in the morning before dosing and the weights are averaged by groups. It has been found necessary to take expectancy of weight increase into account in figuring dosages in advance, since young ducklings make considerable growth during the six-day drugging period. At first, in the fall of the year, the host-weight employed in calculating the doses for a particular group during the first three days was 112.5 per cent of the average weight of the group on the day of inoculation, but after artificial lighting was maintained until 9:00 P.M. this figure was increased to 116.67 per cent. The doses for the second three days are 1.4x those for the first three days if the mean of the average weights for the first three days is 15 per cent, or less, greater than the average weight on the first day of dosing, or 1.6x those for the first three days if the mean of the average weights for the first three days is 16 per cent, or more, greater than the average weight on the first day of dosing. The regular practice is to include the doses for the first three days in 1 cc. of liquid and those for the last three days in 1.4 cc. or 1.6 cc. of liquid. Fresh solutions of all water soluble drugs are prepared every forty-eight hours and kept in the refrigerator.

The actual dosage (in terms of the base of the drugs) for the group is derived by the following formula:

$$\frac{1000 \times \text{mean of 12 doses (in mg. of the base)}}{\text{mean of the 6 average weights (in grams)}}$$

The ducklings in each group are selected to insure as uniform weight as possible. Five ducklings are ordinarily used in each drugged group, and six to eight in the undrugged control group. If, however, the amount of drug available is very limited, four ducklings make up the test group. Experience shows that the actual dosages, as computed after the dosing period, are satisfactorily close to the intended dosages. Two groups of birds receiving quinine dosages of 8 mg./kg. b.i.d. and 12 mg./kg. b.i.d., respectively, are usually included in each series.

The criterion for assessing activity is the percentage of parasitized red cells on the sixth day after inoculation; that is, the day after the last dose of the drug. If percentages for the control ducks are higher on the fifth day than on the sixth, as is the case more often than not, the former are used instead of the latter. A drug is considered active for purposes of calculating the quinine equivalent if the geometric mean (Marshall, 1946, in Wiselogle, Vol. I, p. 62) of the percentages for the drugged group is half or less the geometric mean of the percentages for the controls. The quinine equivalent of a drug is the ratio of the dosage of quinine required to effect a significant reduction (*i.e.*, 50 per cent or more) in parasitized cells to the dosage of the drug which effects approximately the same reduction.

The number of red cells counted in a particular smear depends upon the intensity of the infection, and is indicated in a table prepared by Dr. W. Clark Cooper based on Gingrich's (1932) formula for obtaining a parasite-erythrocyte ratio with a probable error of 10 per cent.

The possibility of a drug producing anemia and in this way giving a false impression of antimalarial activity is checked by red blood cell counts on birds receiving drugs that appear to have shown antimalarial activity and by observing relative numbers of erythroblasts. The necessity for observing such precautions was impressed upon us graphically in a test of the antimalarial properties of azobenzene with the dosage at 170 mg./kg. The five- and six-day smears showed less than one parasite per field, but practically all the red cells were erythroblasts.

The ducklings were kept under observation for eighteen days after inoculation to observe the mortality; or, conversely, as stated in the table, the survival.

RESULTS AND DISCUSSION

Table 1 shows that twenty-eight of the thirty-five drugs and all of the four plant materials were inactive at the maximum doses administered. Host mortality in the test groups receiving these materials was fairly comparable with that in the control groups. The sulfonamides

TABLE 1

GEOMETRIC MEANS OF PER CENTS OF PARASITIZED CELLS (% PC), NUMBER OF DUCKS SURVIVING EIGHTEEN DAYS AFTER INOCULATION (SUR), AND QUININE EQUIVALENTS (Q).

Drug Nos.	Names of Drugs	Test Series			Controls	
		% PC	Q	Sur	% PC	Sur
SN Nos.						
359	Quinine-monohydrochloride, dihydrate		1.0			
-3-4						
6221	<i>Aspidosperma nitidum</i>	86	inactive	3/5	87	3/6
8505	3,4-dichloro- α -(dioctylaminomethyl)-benzyl alcohol	3	0.4	5/5	87	2/4
11639	2,5-dichloro- α -(dioctylaminomethyl)-benzyl alcohol, hydrochloride	2	0.8	5/5	84	3/8
-4						
DR Nos.						
15442	α -(<i>sec</i> butylaminomethyl)-7-chloro-2-(<i>p</i> -chlorophenyl)-8-methyl-4-quinolinemethanol, hydrochloride	5	10.0	5/5	84	3/8
-4						
15469	5,8-dichloro- α -(diethylaminomethyl)-2-phenyl-4-quinolinemethanol, hydrochloride	3	0.9	4/5	83	3/6
-4						
15534	8-(5-isopropylaminoamylamino)-7-methoxyquinoline	88	<0.14	2/5	81	1/8
15544	<i>Micromeria graeca</i> var. <i>consentia</i>	76	inactive	2/5	72	0/7
15545	<i>p</i> -acetylphenoxyacetic acid	67	<0.03	0/4	84	1/7
15546	N-acetylanthranilic acid	84	<0.04	1/5	84	1/7
15547	5-benzyl-8-quinolinol	77	<0.03	0/4	84	1/7
15548	(4-amino-6-hydroxy-2-pyrimidyl)mercapto acetic acid	82	<0.08	0/4	84	1/7
15549	β -[(4-amino-6-hydroxy-2-pyrimidyl)mercapto]propionic acid	62	<0.08	2/4	84	1/7
15550	N',N''- <i>p</i> -phenylenebis[N ⁴ -acetyl-sulfanilamide]	80	<0.03	1/5	72	0/7
15551	4-(2-ethylenedioxybis(N-butylbenzenesulfonamide)	74	<0.14	0/4	72	0/7
15552	4'-(2-thiazolylsulfamyl) gallanilide	81	<0.05	1/5	72	0/7
15553	N,N'- <i>p</i> -phenylenebis- <i>p</i> -nitrobenzenesulfonamide	78	<0.14	2/5	72	0/7
15554	4-benzylideneaminoantipyrine	82	<0.02	3/5	87	3/6
15556	2,8-diaminotridecahydro-3,7-phenothiazine disulfonic acid	81	<0.03	2/5	84	1/7
15557	dibenz[c,g][1,2,5,6] trithiazocine	80	<0.03	2/5	87	3/6
15558	"Hetrazan" (see text)	76	<0.03	2/5	72	0/7
15559	α -(diethylaminomethyl)-9-acridanmethanol	78	<0.14	0/5	72	0/7
15561	5-chloro- α -dihexylaminomethyl-2-phenyl-4-quinolinemethanol, dihydrochloride	4	2.00	5/5	79	4/7
15562	4-dimethylaminochalcone	68	<0.03	0/5	72	1/5
15565	<i>Pycnanthemum pilosum</i>	84	inactive	1/5	87	3/6
15566	2-phenyl-1,3-benzodioxan-4-one	82	<0.02	2/5	72	1/5
15568	2-methyl-3,1-benzoxathian-4-one	85	<0.03	2/5	87	3/6
15569	2-phenyl-3,1-benzoxathian-4-one	76	<0.02	2/5	87	3/6
15570	2,4,6-tris(<i>p</i> -dimethylamino phenyl)s-trithiane	75	<0.05	3/4	87	3/6
15571	1,1,1-trichloro-2,2-bis (5-propoxycarvacryl)-ethane	71	<0.04	2/5	84	1/7
15572	1,1,1-trichloro-2,2-bis (5-ethoxycarvacryl)-ethane	70	<0.04	2/5	72	1/5
15573	2-methyl-4-naphtho[2,3-d]- <i>m</i> -dioxin-4-one	68	<0.03	2/4	84	1/7
15574	2,8-dimethyl-1,3-benzo dioxan-4-one	80	<0.02	0/4	84	1/7
15575	2-methoxy-5,6,7,8-tetrahydro-9,10-acridone	62	<0.15	0/5	79	0/7
15582	5-chloro-2-(<i>p</i> -chlorophenyl)- α -diethylaminomethyl-4-quinolinemethanol dihydrochloride	9	0.75	1/5	79	0/7
15609	gallium (III) salt of lactic acid	84	<0.15	2/5	79	4/7
15614	N'-(5-cyclopropyl-1,3,4-thiadiazol-2-yl)-sulfanilamide	74	<0.03	2/5	72	1/5
15615	4-(2-naphthyl)morpholine	78	<0.14	0/5	79	0/7

tested were disappointing, but an inspection of Wiselogle's tables (1946, Vol. II, pt. 2) reveals comparable lack of antimalarial activity in other related compounds. It is of special interest that DR 15,558-4 ("Hetrazan," or 1-diethylcarbamy-4-methyl-piperazine hydrochloride), which is known to have antifilarial properties, revealed no antimalarial activity at Q 0.03. DR 15,575 is being reported inactive at Q 0.15 because the sixth day count was high, still it seemed to be on the verge of demonstrating activity. The fourth, fifth, and sixth day percentages were, respectively, 17.5, 32.8, and 62.6. These values may be compared with others obtained in the same series; viz., 43.7, 79.2, and 70.7, respectively, for the untreated controls, and 37.4, 78.6, and 76.4, respectively for the groups receiving SN 6221 in the ration at the 1 per cent level. DR 15,534, prepared by Dr. R. C. Elderfield of Columbia University, was the second 7-substituted 8-amino-quinoline to be tested, the first having been DR 15,305 [7-methyl-8-(5-isopropylamino-pentylamino)-quinoline] on which Q 0.25 was reported by Dr. A. R. Richardson after the G4 test against *P. lophurae* in ducks (Personal communication from R. C. Elderfield). Since Q's of from 20 to 80 have been reported for several 5-methoxy-8-amino-quinolines, e.g., SN 15,085 with Q 80 appearing in Wiselogle (1946), it is exceedingly disappointing that this 7-methoxy compound is inactive in the W-1 test at Q 0.1444.

Of the seven active drugs, quinine (SN 359-4-3) is, of course, the standard. The 2-phenyl-4-quinolinemethanols demonstrated antimalarial activity with Q 10 for DR 15,442-4, Q 0.9 for DR 15,469-4, Q 2 for DR 15,561-4, and Q 0.75 for DR 15,582. Quite a few 2-phenyl-4-quinoline-methanols have been tested previously (Wiselogle, 1946, Vol. 2, pt. 2, pp. 1074-1089), and many of them show a high antimalarial activity against *P. lophurae* as well as against other bird malaras.

The other two active drugs, SN 8,505 and SN 11,639-4, were α -(dioctylaminomethyl) benzyl alcohols, and Q's of 0.4 and 0.8, respectively, are being reported for them. The unsubstituted α -(dioctylaminomethyl) benzyl alcohol has shown no antimalarial activity at the various levels so far tested (Wiselogle, 1946, Vol. II, pt. 1, p. 282), but the *p*-hexyl compound showed Q 0.3 in the D-1 test (*ibid.*, p. 283). The *p*-flouro compound showed very little activity (*ibid.*, p. 323), and the *p*-iodo gave Q 0.2 against *P. gallinaceum* in the Q-4 test (*ibid.*, p. 353).

DR 15,544, *Micromeria graeca*, var *consentia*, a plant of the LABIATAE family, is a native of Italy. A solution was prepared by steeping 1,000 mg. of the powdered plant in 100 cc. of distilled water. Ducks inoculated on the twelfth day of life received 2 cc. of the solution t.i.d. for three days, then 3 cc. t.i.d. for three days. The infection was unaffected.

SN 6,221, *Aspidosperma nitidum*, is a plant of the APOCYNACEAE family, grown in Brazil. The powdered plant received by us was ground in a mortar and fed in the ration for six days at the 1 per cent level in the first test and at the 5 per cent level in the second test. Though the mixture was eaten well, the infection was unaffected.

Although two tests were made with DR 15,565, only the results of

the first are shown in Table 1. The tea for the first test was made by steeping 0.5 oz. of the herb *Pycnanthemum pilosum* in 237 cc. of distilled water for 10 min. That for the second test was made with twice as much herb in the same amount of water. The dosage in the first test was 1 cc. b.i.d. during the first three days and 1.8 cc. b.i.d. the second three days. The dosage in the second test was 1 cc. t.i.d. the first three days and 1.6 cc. the second three days. The solution proved inactive in both tests although several times as much extract was administered in the second test as in the first.

SUMMARY

There are presented in this report data on the evaluation of anti-malarial activity of thirty-five chemical compounds and three plant materials.

LITERATURE CITED

- BISHOP, A.
1942. Chemotherapy and avian malaria. *Parasitology* 34:1-54.
- GINGRICH, W.
1932. Immunity to superinfection and cross-immunization in malarial infection of birds. *Jour. Prev. Med.* 6:197-246.
- MARSHALL, E. K.
1946. Pharmacological investigations of potential antimalarial drugs. Chap. II of Wiselogle, 1946 (see below).
- , LITCHFIELD, J. T., AND WHITE, H. J.
1942. Sulfonamide therapy of malaria in ducks. *Jour. Exper. Pharm. a. Therap.* 75:89-104.
- DAVEY, D. G.
1946. The use of avian malaria for the discovery of drugs effective in the treatment and prevention of human malaria. I. Drugs for clinical treatment and clinical prophylaxis. *Ann. Trop. Med. a. Parasit.* 40:52-73.
- ROEHL, W.
1926. Die Wirkung des Plasmodiums auf die Vogelmalária. *Arch. f. Schiffs- u. Trop.-Hyg.* 30: B hft. 311.
- WISELOGLE, F. Y.
1946. A Survey of Antimalarial Drugs, 2 Vols. Ann Arbor, Mich.

LIFE HISTORY AND MANAGEMENT OF THE YELLOW PIKEPERCH, *STIZOSTEDION V. VITREUM* (MITCHILL), OF CLEAR LAKE, IOWA¹

ROBERT E. CLEARY²

Department of Zoology and Entomology, Iowa State College

Received August 6, 1948

The yellow pikeperch, *Stizostedion vitreum vitreum* (Mitchill), is one of the most sought-after game fish in Iowa. Since few Iowa Lakes are large enough or have suitable limnological features for the growth and perpetuation of this fish, the strain of heavy fishing or changes in the environment may endanger the populations in some of the lakes. Clear Lake, in Cerro Gordo County, was chosen as the site of investigation since it provides much sport fishing and is one of the most popular resort areas in the state. This north-central Iowa lake, with an area of 3,643 acres, is the third largest lake in Iowa. It is a highly productive, eutrophic, shallow body of water with a maximum depth of twenty-two feet.

MATERIALS AND METHODS

This study is based upon scale samples and other data collected in 1941, 1942, and 1943, and from June 20 to September 1, 1947. A variety of gear was used in making the 1947 collection (Table 1) and various

TABLE 1
LENGTHS OF CLEAR LAKE YELLOW PIKEPERCH TAKEN BY VARIOUS GEAR,
JUNE TO SEPTEMBER, 1947

Standard Length in Millimeters	Total Length in Inches	Experimental Gill Net	30 Foot Seine	500 Foot Seine	Angling	Total
70-99	3.4- 4.7	.....	5	2	.....	7
100-149	4.8- 7.1	.....	.....	16	.....	16
150-199	7.2- 9.5	10	1	3	.....	14
200-249	9.6-11.9	12	3	10	2	27
250-299	12.0-14.3	15	.....	4	28	47
300-349	14.4-16.7	20	1	2	26	49
350-399	16.8-19.1	19	.....	.....	19	38
400-449	19.2-21.5	3	.....	.....	6	9
450-499	21.6-23.9	1	.....	.....	.....	1
500-549	24.0-26.3	1	.....	.....	.....	1
Total		81	10	37	81	209

¹ Technical Paper No. 13 of Iowa Cooperative Fishery Research Unit, Project No. 39 sponsored by Industrial Science Research Institute of Iowa State College and the Iowa State Conservation Commission.

² Now with the Iowa State Conservation Commission.

habitats were investigated to insure a complete coverage of size and age groups. About 37 per cent of the yellow pikeperch were taken in gillnets; 37 per cent by angling; and 26 per cent by seining. Three 100-foot sections of experimental gillnet were used with mesh size varying from $\frac{3}{4}$ inch to 4 inches (bar measure). In gillnetting two general habitats were sampled: deep water (8-15 feet), and shallow water (2-3 feet). The nets were checked every two hours and all specimens were returned to the water after the pertinent information was recorded. All shore areas were seined with a 30-foot common sense minnow seine at various times throughout the summer, and on August 19, 1947, the State Conservation Commission survey crew sampled the gently sloping areas of the lake with a 500-foot seine ($\frac{1}{4}$ inch mesh). Angling catches were sampled throughout the season.

The 1941, 1942, and 1943 specimens were collected by Dr. Reeve M. Bailey, Harry M. Harrison, Jr., and Everett B. Speaker (Bailey and Harrison, 1945), using the same type of equipment as was employed in the 1947 investigation.

Scale samples were taken in the field and none of the specimens was preserved. The scales were removed from either side of the body and from an area just caudad the tip of the pectoral fin as it was extended caudally and dorsally to the lateral line. No attempts were made to determine sex and maturity of the individual specimens in the 1947 catch. Total, fork, and standard lengths were recorded to the nearest 0.1 inch. Specimens of less than one pound were weighed on a spring platform balance with a 500 gram capacity, and those over one pound, on a Salter spring scale with an eight pound capacity.

Standard length, measured on a straight line from the tip of the snout to the end of the hypural plate, was used in all calculations for growth analysis. In addition, total length, measured on a straight line from the tip of the snout to the tip of the compressed lobes of the caudal fin, and the fork length, measured from the tip of the snout to the center of the fork of the caudal fin were recorded. On the basis of the measurements of 215 yellow pikeperch, the following conversion factors were computed:

$$\begin{aligned}\text{Fork length} &= 1.127 \text{ standard lengths} \\ \text{Total length} &= 1.198 \text{ standard lengths} \\ \text{Total length} &= 1.065 \text{ fork lengths}\end{aligned}$$

The ages and growth rates of the pikeperch were determined from examinations and measurements of the annuli of the scales (Fig. 1). These annuli were for the most part easily recognizable and the fact that they were truly year marks was verified by methods similar to those used by Carlander (MS), Hile (1941), and Van Oosten (1929).

Of 52 specimens taken between June 20, 1947, and July 1, 1947, only eight failed to show a new annulus near the anterior radius of the scale. It is therefore probable that annulus formation for 1947 was

accomplished in late May or June. Carlander (MS) states that only one of sixty-two pikeperch collected at Lake of the Woods in the last half of June, 1940, had not completely formed a new annulus. It is possible that in Clear Lake the annuli are usually formed earlier than

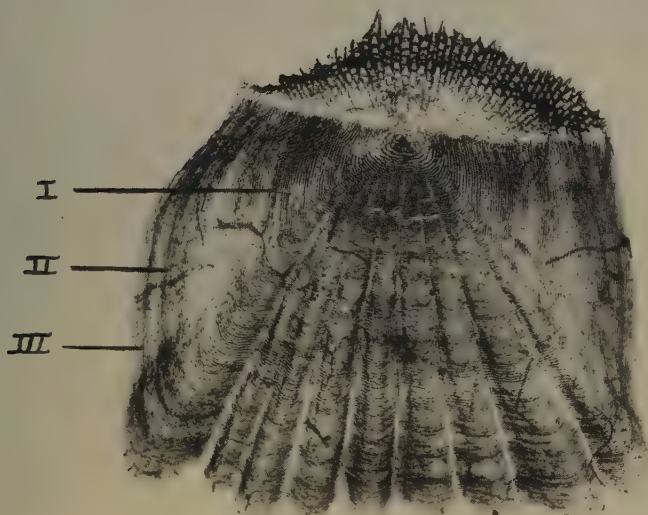


FIG. 1.—Scale from a three-year-old pikeperch, Clear Lake, Iowa.

these data show, because the spring of 1947 was especially cold which would tend to delay the resumption of growth.

BODY-SCALE RELATIONSHIP

Much of the earlier work on calculation of growth from scale methods was based on the assumption that the body-scale relationship was a direct proportion. Later evidence, however, indicated the need for determining the body-scale relationship for each species and even for different populations of the same species. Carlander (1945) found the body-scale relationship in the pikeperch of Lake of the Woods to be represented by a third degree polynomial. Schloemer and Lorch (1942), in their study of pikeperch in Wisconsin, used the straight line relationship on the basis of unpublished evidence.

The body-scale relationship of 215 yellow pikeperch from Clear Lake (Fig. 2) was determined by plotting the mean body lengths at 20 millimeter intervals against the mean anterior radii of the scales and fitting a line to the data by the least squares method. A straight line having an intercept on the length axis of 35.7 millimeters and a slope of 2.35 gave a satisfactory fit. Consequently, growth calculations were made on a direct proportion basis using 35 millimeters as a base rather than zero (Carlander and Smith, 1944). Presumably the scale is formed when the fish is about 35 millimeters in standard length or 43 millimeters in total length.

GROWTH RATE

Scales from 319 yellow pikeperch collected in 1941, 1942, 1943, and 1947 at Clear Lake were used to determine growth rate. The most rapid growth in length occurs in the first year of life and the annual increment decreases each year thereafter (Tables 2 and 3). There is no pronounced leveling off of the growth rate in later years of life. Carlander (1945) found that the Lake of the Woods pikeperch showed a nearly constant annual growth increment after the fourth year.

TABLE 2
AVERAGE CALCULATED LENGTHS OF YELLOW PIKEPERCH IN EACH AGE GROUP, COLLECTED AT CLEAR LAKE, 1941 TO 1943

A. October, 1941.

Age Class	Number Examined	Standard Length in mm, at Each Annulus						Standard Length at Capture
		1	2	3	4	5	6	
I.....	8	141						218
II.....	38	113	210					256
III.....	2	118	192	272				320
IV.....	4	140	223	290	355			404
VI.....	1	119	194	298	372	429	480	510

B. April, 1942.

III.....	5	110	193	247*				247
IV.....	26	140	250	319	355*			355
V.....	21	135	231	297	353	396*		396
VI.....	5	162	259	339	400	453	478*	478

C. July, 1943.

I.....	1	165						212
II.....	1	125	252					276
III.....	6	116	212	279				308
IV.....	5	133	244	319	379			406

* The annuli had not yet formed for the current year, but the age classes are designated as if the annuli were just formed at the edge of the scales.

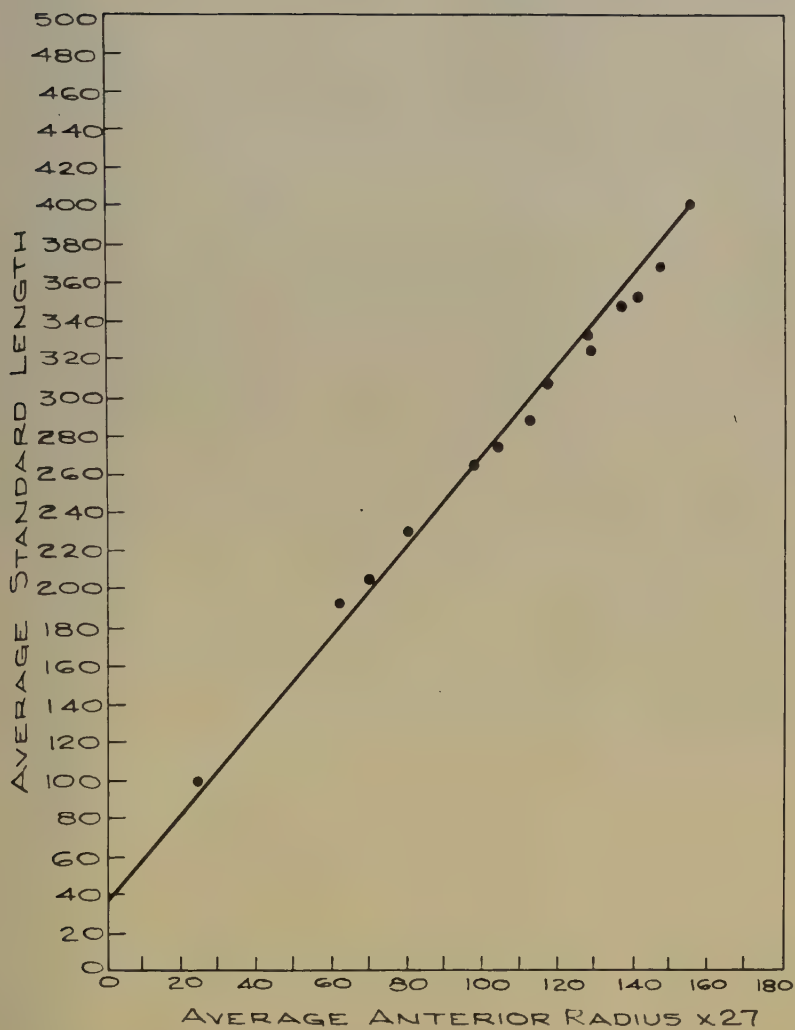


FIG. 2.--Body-scale relationship of yellow pikeperch from Clear Lake, Iowa.

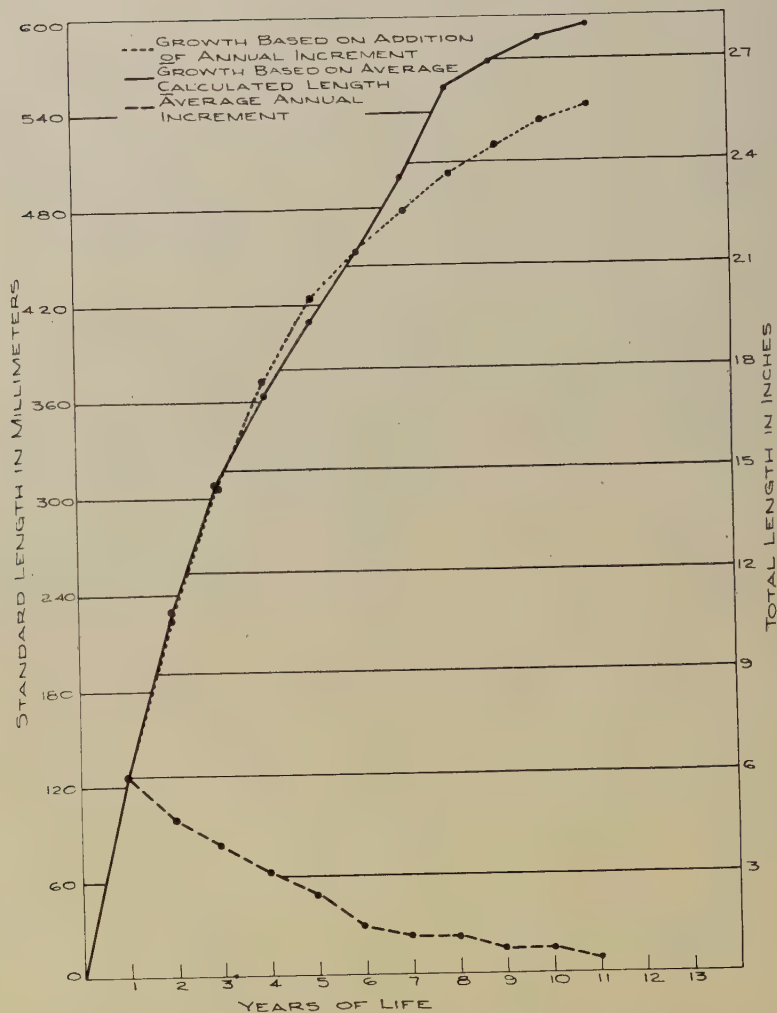


FIG. 3.—Rate of annual growth of Clear Lake pikeperch in the 1935 to 1946 year classes.

Lee's phenomenon of apparent change in growth, as shown in the calculated growth rates, was significant in the first six age classes of the 1947 catch. Van Oosten (1929) and Hile (1936) offer several explanations for this phenomenon but lack of adequate comparative data prevents a thorough discussion of the manifestation of the phenomenon in the present data.

Table 4 shows comparative data on the growth of the yellow pikeperch in various sections of the midwest. The Clear Lake average is somewhat higher than that reported from other waters except Norris Reservoir. In the Norris Reservoir (Eschmeyer and Jones, 1941), the phenomenal growth of the yellow pikeperch can be attributed in part to the virgin waters of the impoundment and to a limited population density. However, they report a regressive trend in growth rate and state

TABLE 3
AVERAGE CALCULATED LENGTHS OF YELLOW PIKEPERCH IN EACH AGE GROUP COLLECTED AT CLEAR LAKE, JUNE TO SEPTEMBER, 1947

Age Class	Number Examined	Standard Length in mm. at Each Annulus											Standard Length at Capture
		1	2	3	4	5	6	7	8	9	10	11	
I.....	40	133											203
II.....	58	122	244										280
III.....	64	117	238	317									340
IV.....	18	108	216	301	357								371
V.....	5	110	197	288	350	400							423
VI.....	2	106	173	275	346	375	402						425
VII.....	2	112	198	267	342	396	442	466					474
X.....	1	141	320	371	425	490	504	527	553	571	590		599
XI.....	1	176	309	395	456	493	512	538	560	574	586	595	605

Grand Average of Tables 2 and 3. (319 Fish)

Standard Length in mm.	124	230	308	364	409	454	499	557	573	588	595
Average Annual Increment	124	109	75	52	46	30	24	24	16	16	9
Growth Based on Summation of Annual Increment	124	233	308	360	406	436	460	484	500	516	525
Total Length in Inches	5.9	10.9	14.5	17.2	19.3	21.4	23.6	26.3	27.0	27.7	28.1

that their study fails to indicate at what point the growth rate will level off. The high calculated growth for the first year in the Lake of the Woods data (Carlander, 1945) is probably the result of the differences in methods of calculation. It is apparent that the growth rate is more rapid in the south and slower in the north, probably due to the longer growing season in the south. A similar trend was noted in a large series of Minnesota lakes (Eddy and Carlander, 1939).

The available data fail to show dominant year classes such as have been reported in various other populations and species. The prevailing conditions in the lake and the fishing pressure may trend toward a

TABLE 4
COMPARISON OF YELLOW PIKEPERCH GROWTH IN VARIOUS AREAS

Location	Number Examined	Calculated Total Length in Inches at Each Year								
		1	2	3	4	5	6	7	8	9
Lake of the Woods Carlander, (1945) . .	2898 *	6.4	9.3	11.5	13.5	14.9	16.7	18.3	19.9	21.6
Minnesota Lakes Eddy-Carlander, (1939)	6599	4.6	8.6	12.0	15.0	18.1	20.5	22.9	25.2	26.7
Trout Lake Schloemer-Lorch, (1942)	427	5.3	9.7	13.7	16.6	19.0	20.7	21.7	22.3	23.1
Iowa Lakes Carlander, (1948) . .	216	5.0	9.2	12.4	15.0	17.1	18.6	19.9	21.5	23.2
Norris Reservoir Eschmeyer-Jones, (1941)	96	8.3	16.0	20.5						
Clear Lake	319	5.9	10.9	14.5	17.2	19.3	21.4	23.6	26.3	27.0

* Computed data for these fish corrected for body-scale relationship. All others are based on straight line relationship.

balanced environment favoring a fairly constant production of yellow pikeperch.

AGE AND GROWTH AT MATURITY

No sex or maturity data were collected in 1947, but the 1941 to 1943 collections indicate that over 80 per cent of the male pikeperch mature at two years of age and at a total length of 12 inches. The female, however, does not mature until the third year and at a size of 13.3 to 14 inches in total length. Carlander (1945) found that male pikeperch of Lake of the Woods mature when they are 11.4 to 13.7 inches in total length and the majority of the females mature at 17.3 inches in total length. Deason (1933) found the male pikeperch of Lake Erie maturing between 13 to 13.5 inches and 93 per cent of the females maturing between 14 to 14.5 inches in total length. The Clear Lake population matures at both an earlier age and shorter length than either of the above populations.

LENGTH-WEIGHT RELATIONSHIP

It has been shown (Hile, 1941) that the length-weight relationship of various fish may in general be expressed by the following equation:

$$W = CL^n$$

where C = a constant
and n = a constant

The values of C and n for the 1947 data were determined by the least squares method using the logarithms of the average length and weight (Table 5). The mathematical relationship between the standard

length and weight of Clear Lake pikeperch can be described by the following formula:

$$W = 1.146 \times 10^{-6} L^{3.0445}$$

This empirical formula approximates that of a cubic parabola which indicates that the weight increases as the standard length raised to the third power.

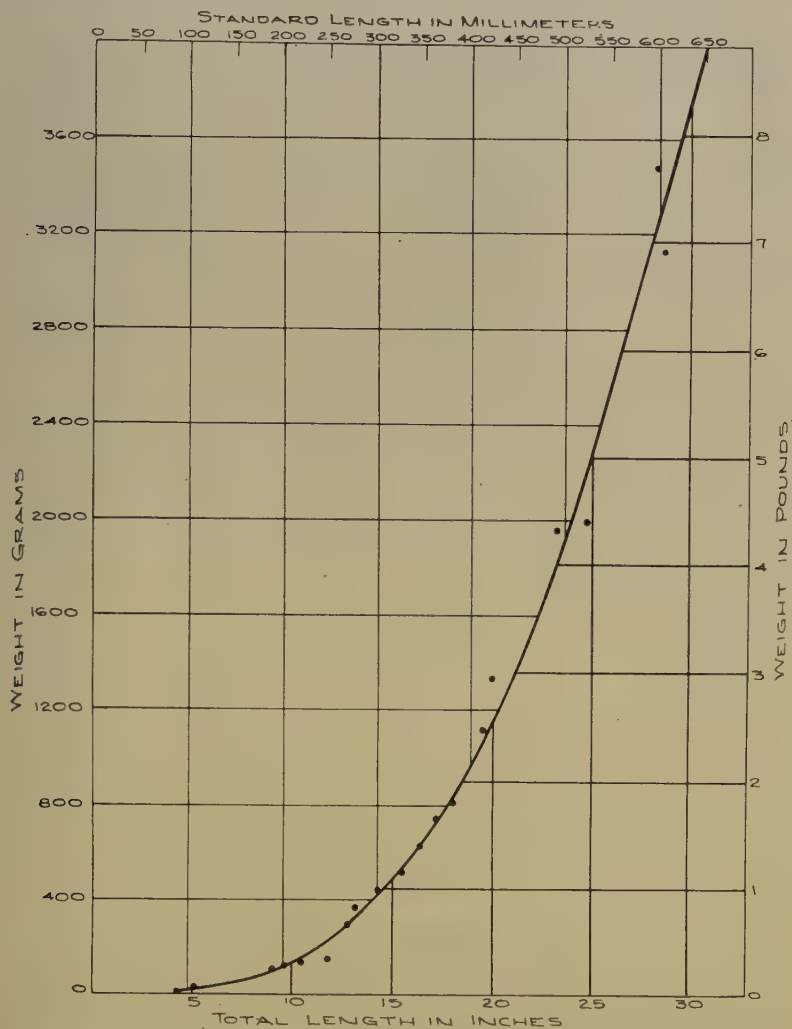


FIG. 4.—The length-weight relationship of yellow pikeperch from Clear Lake, Iowa.

As an indication of "general well being" or relative plumpness in fish, several authors have used the coefficient of condition, K , where

$$K = \frac{W 10^5}{L^3}$$

if W = weight in grams
and L = standard length in millimeters

The average K of the Clear Lake pikeperch taken in 1941, (19 fish) was 1.461; in 1942, (61 fish) 1.549; and in 1947, (143 fish) 1.494 (Table 5), giving a grand average of 1.507 for 217 fish. The average K for Clear

TABLE 5
THE LENGTH-WEIGHT RELATIONSHIP AND COEFFICIENT OF CONDITION, K , OF CLEAR LAKE
YELLOW PIKEPERCH, JUNE TO SEPTEMBER, 1947

Average Standard Length in Millimeters*	Number of Fish	Weight in Grams			Average K
		Average	Range	Calculated**	
90	4	10	7-14	10	1.37
110	4	21	12-25	19	1.48
194	13	110	85-128	106	1.50
206	23	128	85-156	127	1.46
222	2	149	142-155	160	1.36
252	2	166	162-170	235	1.05
271	13	296	227-383	293	1.49
280	11	369	340-397	324	1.54
307	12	435	397-482	428	1.50
329	14	523	454-624	529	1.47
350	21	635	482-765	638	1.48
367	9	751	652-950	737	1.52
385	4	805	723-907	853	1.42
412	5	1123	680-1531	1048	1.59
427	2	1347	1304-1389	1169	1.73
493	1	1970	.....	1807	1.64
528	1	1999	.....	2231	1.36
599	1	3487	.....	3276	1.62
605	1	3147	.....	3377	1.42
Total	143			Grand Average	1.494

* Fish were grouped by 20 millimeter size classes.

** $W = 1.146 \times 10^6 L^{3.0415}$.

Lake pikeperch is higher than the average, 1.446, reported for Trout Lake, Wisconsin (Schloemer and Lorch, 1942) and 1.470 reported for Lake of the Woods, Minnesota, by Carlander (1945). It would therefore appear that the Clear Lake pikeperch are full-bodied as well as fast-growing.

It is apparent from Table 6 that while the annual length increment decreases with each successive year, the annual weight increment increases each year until it reaches a peak in the fifth year. The general trend is regressive after the fifth year and the fluctuations are probably due to the small number of specimens.

TABLE 6
COMPARISON BETWEEN LENGTH AND WEIGHT AT EACH ANNULUS OF 319
CLEAR LAKE YELLOW PIKEPERCH

Age in Years	1	2	3	4	5	6	7	8	9	10	11
Standard length in millimeters..	124	230	308	364	409	454	499	557	573	588	599
Comparative weight in grams.....	27	178	432	719	1025	1409	1879	2626	2862	3096	3276
Average annual length increment in millimeters..	124	109	75	52	46	30	24	24	16	16	9
Average annual weight increment in grams.....	27	153	247	270	312	265	262	330	232	249	212

MANAGEMENT DISCUSSION

In general, the ultimate goal of any fishery management project is to furnish an adequate source of fast growing, well conditioned fish. Since the Clear Lake pikeperch appear to be a hardy, rapid-growing population, it would seem that favorable environmental conditions are present. Even though subjected to heavy fishing pressure, the pikeperch population remains at a fairly constant level.

Natural reproduction in Clear Lake is supplemented by artificial propagation and stocking activities by the State Conservation Commission. During the last ten years over 250 million pikeperch fry have been stocked in yearly amounts varying from 12 to 44 million per year. In addition, over 60,000 fingerlings reared in the Commission's ponds have been stocked in the last seven years with yearly plants ranging

TABLE 7
NUMBER AND AVERAGE SIZE IN SAMPLE OF CLEAR LAKE PIKEPERCH TAKEN BY ANGLERS IN THE
SUMMER OF 1947

Number of Specimens	Age Class	Average Total Length in Inches	Percentage of Catch
29.....	II	12.8	35.8
39.....	III	15.7	48.1
9.....	IV	17.1	11.1
1.....	V	19.6	1.2
2.....	VI	19.9	2.5
1.....	VII	22.0	1.2

Total—81

Average—15.0

from 5,000 to 20,000 fish.¹ The economic feasibility of the present stocking program should be tested by investigating the survival rate of the artificially planted stock. Alternate planting experiments such as those carried on by Dahl (1934) and others should indicate whether stocking has any appreciable effect on the population.

Most of the yellow pikeperch caught by anglers are less than four years old (Table 7). It has been pointed out that most of the female pikeperch do not spawn until three years old. With the present fishing pressure and the 12-inch size limit, many of the females are caught before they have an opportunity to spawn. At present, the population seems to be maintaining itself. If, in the future, the population declines as a result of inadequate spawning stock, it may be advisable to increase the size limit so that the females are protected from fishing until they are large enough to have spawned at least once.

The 1948 fishing regulations which removed the size limits on all the species in the lake with the exception of the black bass, northern pike, and yellow pikeperch, and reduced the possession limit from eight to five in the latter two species should benefit the pikeperch by reducing the fishing pressure on this species and also by reducing the numbers of other species which compete with the young pikeperch for food and space.

SUMMARY AND CONCLUSIONS

1. The study of Clear Lake yellow pikeperch was based on 319 specimens collected in 1941, 1942, 1943, and 1947.

2. Of fifty-two specimens taken between June 20, 1947, and July 1, 1947, only eight failed to show an annulus near the anterior radius of the scale. It is therefore probable that the 1947 annulus was formed in late May or June.

3. The body-scale relationship can be described as a linear regression having a Y-intercept (length axis) of 35.7 millimeters (standard length) and a slope of 2.35.

4. The most rapid growth in length occurs in the first year of life and the annual growth increment decreases each year thereafter.

5. Lee's phenomenon of apparent decrease in the calculated growth rate was observed in the first six year classes in the 1947 catch.

6. The average growth rate of Clear Lake pikeperch is higher than that in various other sections of the midwest, probably due to the longer growing season and the favorable environmental conditions in Clear Lake.

7. The present data fail to show dominant year classes in the Clear Lake pikeperch.

8. The mathematical relationship between standard length and weight can best be described by the empirical formula:

$$W = 1.146 \times 10^{-6} L^{3.0445}$$

¹Information furnished by Everett B. Speaker, Superintendent of Fisheries, Iowa State Conservation Commission, March, 1948.

9. The average coefficient of condition, K , for 217 specimens was 1.507, which is higher than that reported for yellow pikeperch in other waters.

10. The annual weight increment reaches a peak in the fifth year of life and decreases each year thereafter.

11. The male pikeperch mature at a shorter length and at an earlier age than do the females.

12. Of eighty-one fish taken by anglers in 1947, 83 per cent were less than four years old.

13. If, in the future, the population declines as the result of inadequate spawning stock, it may be advisable to increase the size limit to protect the females until they have spawned once.

14. The 1948 removal of size limits on fish other than black bass, northern pike, and yellow pikeperch should benefit the latter species by reducing fishing pressure and competition for food.

ACKNOWLEDGEMENTS

The author is deeply indebted to Dr. Kenneth D. Carlander, Department of Zoology and Entomology, for aid in collecting and interpreting data; to Dr. H. M. Harris, Department of Zoology and Entomology, and Dr. T. G. Scott, U. S. Fish and Wildlife Service, for supervision and encouragement; to Messrs. E. B. Speaker, Charles King, Duane Huey, and E. T. Rose, all of the Iowa State Conservation Commission, for providing excellent working facilities and aid in collecting specimens. Thanks are due Dr. Reeve M. Bailey, Harry M. Harrison, Jr., and Everett B. Speaker, for the use of scale data collected by them in 1941, 1942, and 1943.

The author is also indebted to Mr. C. L. Baumgardner and other Clear Lake anglers whose help and cooperation in gathering specimens and creel census data were of inestimable value.

Lastly, the author wishes to express his gratitude to his wife, whose aid and encouragement expedited both the field work and the preparation of the manuscript.

LITERATURE CITED

BAILEY, REEVE M., AND HARRY M. HARRISON, JR.

1945. The fishes of Clear Lake, Iowa. Iowa State Coll. Jour. Sci. 20(1):57-77.

CARLANDER, KENNETH D.

1945. Age growth, sexual maturity, and population fluctuations of the yellow pikeperch, *Stizostedion vitreum vitreum* (Mitchill), with reference to the commercial fisheries, Lake of the Woods, Minnesota. Amer. Fisheries Soc. Trans. 73:90-103.

1948. Growth of the yellow pikeperch, *Stizostedion vitreum vitreum* (Mitchill), in some Iowa lakes with a summary of growth rates reported in other areas. Iowa State Coll. Jour. Sci. 22(3):227-37.

MS. The walleyes, *Stizostedion vitreum vitreum* (Mitchill), of Lake of the Woods, with special reference to the commercial fisheries. Unpublished PhD. thesis. Univ. of Minnesota Library, Minneapolis, Minn.

AND LLOYD L. SMITH, JR.

1944. Some uses of the nomograph in fish growth studies. Copeia No. 3:157-62.

DAHL, KNUT

1934. Does trout stocking pay? Salmon and Trout Magazine 74:18-26. (In Norwegian, original not seen. English abstract in Prog. Fish Cult. 1:11-14, 1934.)

DEASON, HILARY J.

1933. Preliminary report on the growth rate, dominance, and maturity of the pikeperches (*Stizostedion*). Amer. Fisheries Soc. Trans. 63:348-60.

EDDY, SAMUEL, AND KENNETH D. CARLANDER

1939. The growth rate of walleyed pike, *Stizostedion vitreum* (Mitchill), in various lakes of Minnesota. Proc. Minn. Acad. Sci. 7:44-48.

ESCHMEYER, R. W., AND ALDEN M. JONES

1941. The growth of game fishes in Norris Reservoir during the first five years of impoundment. Sixth North Amer. Wildlife Conf. Trans. 6:222-40.

HILE, RALPH

1936. Age and growth of the cisco, *Leucichthys artedi* (Le Sueur), in the lakes of the northeastern highlands, Wisconsin. U. S. Bur. Fisheries Bull. 48:211-317.

1941. Age and growth of the rock bass, *Ambloplitis rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Trans. Wis. Acad. Sci., Arts, Letters 33:189-337.

SCHLOEMER, CLARENCE L., AND RALPH LORCH

1942. The rate of growth of the wall-eyed pike, *Stizostedion vitreum* (Mitchill) in Wisconsin's inland waters, with special reference to the growth characteristics of the Trout Lake population. Copeia No. 4:201-11.

VAN OOSTEN, JOHN

1929. Life history of the lake herring (*Leucichthys artedi* Le Sueur) of Lake Huron as revealed by its scales, with a critique of the scale method. U. S. Bur. Fisheries Bull. 44:265-428.

THE USE OF VERTEBRAE AS INDICATORS OF THE
AGE OF THE NORTHERN BLACK BULLHEAD *AMEIURUS*
M. MELAS (RAFINESQUE)¹

WILLIAM M. LEWIS

Department of Zoology and Entomology, Iowa State College

Received August 30, 1948

Bullheads, *Ameiurus* spp., can survive in many waters where no other food or game fish can exist. They thus provide fishing in many parts of the country where there is no other fishing. Comparatively little is known of the growth characteristics and environmental requirements of bullheads. This lack of knowledge is a handicap in the management of waters that might provide good bullhead fishing.

Some of the most worthwhile information applicable to management of the scaled fish has been obtained by use of the scale method (Creaser, 1926; Bückmann, 1929; Van Oosten, 1929). Although valuable information for non-scaled fish and those having scales unsuited for age determinations has been obtained from markings of otoliths, subopercular bones, fin rays, and vertebrae, no method of determining the age of bullheads has been reported.

All of these techniques are based on differences in the structure of the scales or bones correlated with changes in growth rate. The portions of scales, otoliths, vertebrae, and some other bony structures laid down during periods of slow growth appear different from those portions laid down when the fish is growing rapidly. In temperate zones, fish show seasonal cycles of growth on their scales or bones which make it possible to determine their ages.

The present study is an attempt to determine the age of black bullheads, *Ameiurus melas melas* (Rafinesque), from variations in vertebral growth.

COLLECTING AND PRESERVING VERTEBRAE

Several methods of preserving and preparing the vertebrae were tried, but the method given below was found to be the most satisfactory.

A longitudinal incision was made on each side of the anterior end of the vertebral column. These incisions extended deep enough to sever the ribs from the vertebrae. Then a transverse incision was made through the fused cervical vertebrae and another between the tenth and eleventh

¹Iowa Cooperative Fishery Research Unit, Technical Paper No. 11, Project No. 42 of the Industrial Science Research Institute of the Iowa State College and the Iowa State Conservation Commission with the cooperation of the U. S. Fish and Wildlife Service. A thesis submitted in partial fulfillment of requirements for Master of Science Degree at Iowa State College.

vertebrae. The section of the vertebral column thus removed was partially cleaned by scraping off the excess tissue. The vertebrae from fish weighing over a pound were disjointed, but those from smaller fish were left connected as a section. In either case the bones were placed in envelopes on which the collection data were recorded and the envelopes were stored under conditions favorable for drying.

After drying about a week the vertebrae which had not been dis-

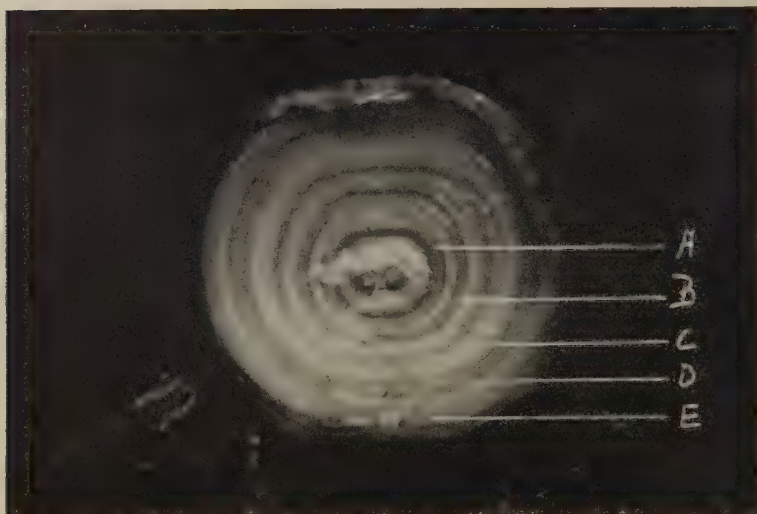


FIG. 1.—Centrum of vertebra of 199 mm. bullhead from Lost Island Lake. The five winter rings (A, B, C, D, E) are in the form of paired lines. Ring A is closely associated with the central area. Compare this latter condition with that of ring C, Fig. 2. $\times 15$.

jointed were broken apart. The dried notochordal tissue usually came out on one centrum and left the adjoining one clean and ready to be examined.

To observe the marks on the surfaces of the centrum it was found that a magnification of $15\times$ with a dissecting microscope was satisfactory. Photographing of the vertebrae showed that it is possible to project a magnified image of them on ground glass. On such an image it is much easier to count and interpret the marks, indicating that such a method might be feasible.

COUNTING VERTEBRAL MARKS

Before counting the vertebral marks it was necessary to establish certain criteria that would distinguish the annual marks from other marks. The seasonal marks of the vertebrae as defined in this study

are in the form of heavy, dark, translucent bands alternating with broad, white, opaque ones (Figs. 1, 2, and 3). The winter growth is represented by the dark bands whereas the summer growth is represented by the white bands. In addition to the true winter marks there occur accessory marks (B of Fig. 3) which may cause confusion. Usually, however, the accessory marks are quite faint or they do not have the depressions of the surface as are characteristic of true winter marks.

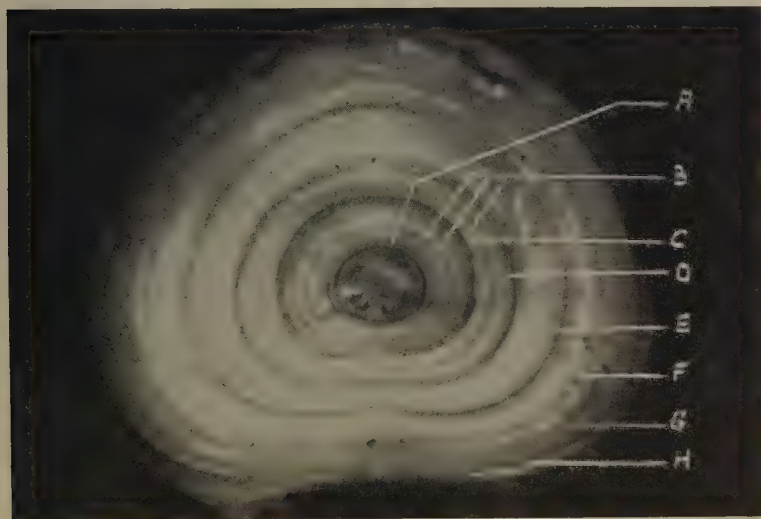


FIG. 2.—Centrum of vertebra of 268 mm. bullhead from Barringer's Slough Outlet Stream. Rings A and B are accessory marks. Rings C, D, E, F, G, and H are winter rings. Ring C, the first annual mark, is well separated from the central area. $\times 15$.

Furthermore, the accessory marks most frequently lie near the center of the centrum and within the area of the first annual ring. Often one accessory mark lies between the first and second winter ring. The annulus may be in the form of double lines (Fig. 1); however, this condition gives very little trouble since the lines are close enough together that there is little question as to their representing one winter's growth.

Locating the first winter ring is quite difficult. At first it would appear A of Figure 1 and A of Figure 2 were of the same status, *i.e.*, both having been laid down during the first winter. Actually, however, A of Figure 1 and C of Figure 2 are presumed to correspond. Observations on many vertebrae indicate that the central area of the vertebra in Figure 1 is so expanded as to cover most of the area lying within the first annual ring, whereas, the central area of the vertebra in Figure 2 is not so expanded, and the area within the first annual ring shows some of the

accessory marks formed during the first year. Thus, in locating the first annual ring one must decide whether or not the central area is expanded. When it is expanded, the first mark outside this area is the first annual ring and hence is a well defined ring quite similar to the winter rings situated further out on the centrum (A of Fig. 1). When the central area is not expanded, there are one or more faint rings lying outside it. These rings are the accessory marks. They appear lighter

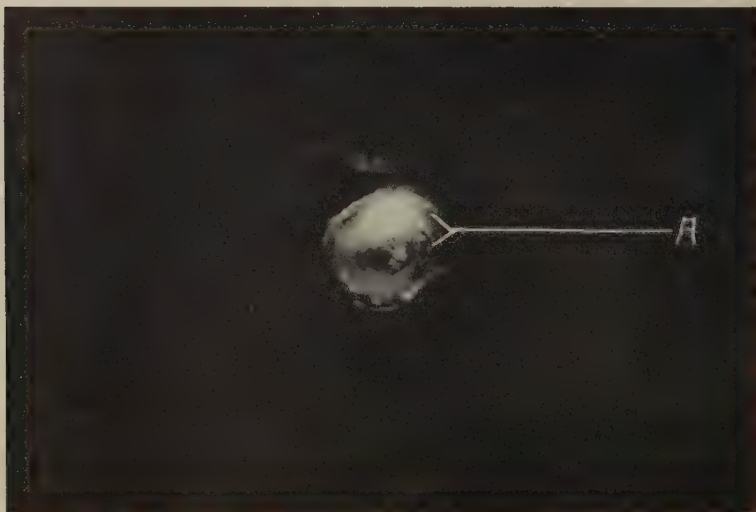


FIG. 3.—Centrum of vertebra of 82 mm. bullhead from the Van Zomeron Pond. The bullhead was known to be a young-of-the-year. The marks indicated by A are accessory marks of the first summer. x 15.

in color and usually are less apt to be associated with depressions in the surface of the centrum. Thus, they are somewhat different from the winter rings situated further out on the centrum (A and B of Fig. 2). When the central area is not expanded, there is more danger of accessory marks being counted.

It can be anticipated that the outer annual rings of older fish will appear weaker and more closely spaced than the rings formed early in life when the fish grew more rapidly. In the outer area accessory marks are less abundant and the depressed nature of the true annual mark is a help in deciding what marks should be counted.

To count the winter rings as defined above, the centra of two or three vertebrae were observed under the microscope. After comparing the count and appearance of the marks of the different centra, a final count was made.

The number of winter rings was considered to indicate the age of the fish in years. In addition a plus sign was added to the fish's age in order to indicate growth beyond the last visible annual ring. For example, a fish listed as being five years old would have on its vertebrae five annual rings, the outer of which would lie at the periphery of the centrum.

In some cases, two independent counts were made of the vertebral

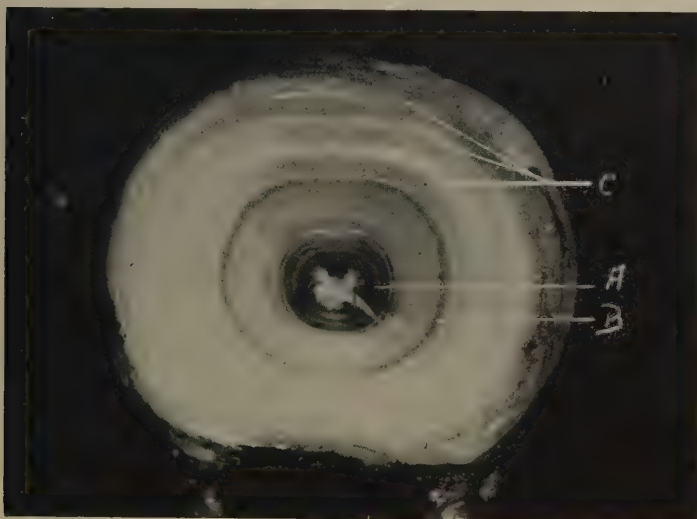


FIG. 4.—Centrum of vertebra of 242 mm. bullhead from the Van Zomeron Pond. The bullhead was known to be one year old. In the central area, A, the accessory lines of the first year are evident. Ring B is the winter ring. Rings C are accessory marks that are evidently variations in structure not accompanied by a difference in color. x 15.

marks. When the second count failed to agree with the first, the age of the fish was not estimated.

VERTEBRAE OF SCALED FISHES

As a first step toward learning whether or not marks on the vertebrae indicate age, vertebral and scale samples of several scaled fish were examined. With twenty-three highfin suckers, *Carpionodes verifer* (Rafinesque), the age as determined from the scales agreed in 40 per cent of the cases with the age determined from the vertebrae. Difficulty was encountered in aging these fish by the scale method and it is felt that ages determined from the vertebrae were as accurate as those obtained by the scale method.

Scales and vertebrae from fourteen smallmouth black bass, *Micropterus dolomieu* Lacépède, were also examined. To make the examinations as impartial as possible, two scale agings were made by experienced persons not familiar with the vertebral agings. Two independent age determinations were also made by the vertebral method. The two scale counts agreed in 86 per cent of the cases as compared to a 50 per cent agreement between the two independent counts of the vertebral marks. In only one case did the ages determined by the two methods differ by more than one year.

These smallmouth black bass came from two different Iowa streams. The scales of smallmouth bass from Coffin Creek were relatively easy to read. Other than the annuli, very few marks occurred on the scales. The marks of the vertebrae were likewise clear and few if any marks other than the annual rings occurred. On the other hand, both the scales and the vertebrae of fish from Lime Creek were difficult to read due to the confusion of marks. The fact that the vertebral marks corresponded so closely with the scale marks supports the assumption that the scale and vertebral marks are caused by the same factor.

VERTEBRAE OF BULLHEADS

In September, 1946, forty northern black bullheads (30 to 60 mm. in total length) were stocked in a new quarter-acre pond on the Van Zomeron farm in Marion County. On August 19, 1947, this pond was seined and bullheads of two principal size groups were caught (Table 1). These fish were of known age. Those of total length 32 to 89 mm. were young-of-the-year; those of total length 235 and 242 mm. were one-year-olds. The young-of-the-year should have had no annual markings on the vertebrae. The one-year-olds should have had one annual mark.

TABLE 1
LENGTH FREQUENCY DISTRIBUTION OF 226 BULLHEADS FROM THE VAN ZOMERON POND

Total Length in Millimeters												
30 to 34	35 to 39	40 to 44	45 to 49	50 to 54	55 to 59	60 to 64	65 to 69	70 to 74	75 to 79	80 to 84	85 to 89	235 to 242
2	5	10	1	9	6	26	56	60	24	22	5	2

By actual microscopic observations the vertebrae of the young-of-the-year were found to have one to three usually faint rings. The vertebrae of one or two specimens had strong enough rings to cause some confusion (Fig. 3).

The vertebrae of the one-year-olds had four or five clear, thin, closely grouped rings near the center of the vertebrae; a very distinct,

relatively broad ring half-way out on the vertebrae; a faint though rather broad ring just slightly out from the distinct ring; and three or four very faint rings between the latter and the periphery of the vertebrae (Fig. 4). The well defined ring half-way out was without doubt the true annual ring. The other rings were accessory marks.

In observing these vertebrae an effort was made to find a difference between the true annual ring and the other marks occurring on the vertebrae. It was found that, at least in this case, the true annual ring was a mark due principally to a difference in color often associated with some depression in the bone surface. The outer accessory marks were primarily the result of depressions alone. The inner four or five clear, thin, closely grouped rings were similar in coloration to the true annual ring, but their position and spacing can undoubtedly be used as a means of considering them false.

The young-of-the-year fish varied in size from 32 to 89 mm., a rather wide variation in length to be found within a one-year class. Raney and Webster (1940) measured young-of-the-year in a cove in Cayuga Lake, New York, and found a similar variation, 41 to 93 mm., on October 10. With such a wide variation it would be difficult to guess the age of the fish from the length frequency distribution. There are two if not three size groups in the young-of-the-year fish from the Van Zomeron Pond (Table 1). When analyzing a population of unknown age, each of these size groups might easily be interpreted as consisting of fish of different ages.

One-year-old fish in this pond showed phenomenal growth, probably due to the uncrowded conditions of the new environment. In other waters with established fish population, it may take several years for bullheads to reach the length these fish reached in one year.

On April 12, 1947, a sample from the 1946 hatch of northern black bullheads was taken from Clear Lake, Cerro Gordo County, Iowa. The mean total length of twenty-four of these specimens was 65.8 mm. The range was 46 to 95 mm. Vertebrae of twenty of the specimens were examined microscopically in an effort to learn the appearance of the vertebral marks of young bullheads. Since the fish were taken at a date earlier than that at which the fish are expected to form a new annual ring, the fish should have had no annual marks on their vertebrae. Upon examination only a few vertebrae were found to have marks that could possibly be called annual rings. Several had one or more extremely faint marks similar to those on the vertebrae of young-of-the-year in the Van Zomeron Pond.

Bullheads from three other ponds, one stream, and one other natural lake were studied (Table 2). The data indicate a fairly good correlation between age and length.

Lost Island Lake, a shallow lake with a surface area of 1,260 acres, has a predominately bullhead population so great that the fish are considered overcrowded and probably stunted. A sample of thirty-three

TABLE 2
AGE OF BULLHEADS FROM THREE PONDS, A STREAM, AND A NATURAL LAKE AS DETERMINED BY
COUNT OF VERTEBRAL MARKS

Age Class	Number of Fish	Total Length in Millimeters	
		Mean	Range
Lost Island Lake, Palo Alto and Clay Co. ¹			
4.....	5	193	190-197
5.....	15	192	184-201
6.....	2	198	196-200
Barringer's Slough Outlet Stream, Clay Co. ¹			
1.....	31	87	68-106
2.....	31	132	103-186
3.....	49	163	103-207
4.....	52	173	134-206
5.....	38	188	157-237
6.....	13	194	169-210
7.....	4	210	197-228
Johnson's Pond 1, Marion Co. ²			
1.....	7	99	93-102
3.....	4	153	135-185
4.....	1	159	.....
Johnson's Pond 4, Marion Co. ²			
1.....	4	115	112-118
2.....	3	182	178-188
3.....	7	181	163-206
4.....	2	188	180-198
5.....	2	195	188-201
Eldon Research Area, Wapello Co. ²			
1.....	16	67	59- 75
2.....	24	121	100-161
4.....	4	160	139-189
5.....	4	206	182-270

¹ Aged only once.

² Stratified sample from many seine hauls.

specimens from this population was taken July 1, 1947. This sample, though small, is quite representative of the size range of the bullheads being taken by anglers at the time of the sampling.

The vertebral ring count indicated these fish were four, five, and six year-olds. These ages are in keeping with the size distribution.

Two counts made on the vertebral marks of the bullheads in three ponds agreed in two-thirds of the specimens. For the most part, the variation was only one year and was due to difficulty in locating the first annual ring. The same difficulty is often encountered in aging fish by the scale methods.

The first three age groups of the Barringer's Slough Outlet population were checked against a length frequency distribution chart and showed good agreement.

The two ponds on the Johnson farm were stocked in 1943. If the ages are correct, some of the fish stocked in pond number 4 were yearlings when stocked. The other fish are all within the expected age classes.

DISCUSSION

In this study it was found that there occur alternate dark and light rings on the centra of bullhead vertebrae. Some of the dark rings are believed to be annual rings laid down each winter. The centra of the vertebrae from some bullheads of known ages had rings that did not correspond to the ages of the fish. In many cases, these additional rings could be distinguished from the annual rings, but further study is needed before the vertebral aging technique can be generally applied.

A tentative estimate of the average growth rate for the northern black bullhead in the waters studied is as follows:

30 to 80 mm.	total length end of first summer
90 to 115 mm.	total length July of second summer
120 to 130 mm.	total length July of third summer
150 to 160 mm.	total length July of fourth summer
170 to 180 mm.	total length July of fifth summer
190 to 200 mm.	total length July of sixth summer
200 to 210 mm.	total length July of seventh summer

The vertebrae of a few channel catfish were studied. In comparison to the bullhead vertebrae, the catfish vertebrae were easier to "read."

SUMMARY AND CONCLUSIONS

1. The vertebral aging technique is not perfected, but it shows promise of being a usable method.

2. Asatisfactory method of preparing vertebrae for aging purposes is to cut the forward end of the vertebral column out and scrape off the excess tissue. The vertebrae of larger fish are disjointed while fresh, whereas those of smaller fish are broken apart after drying.

3. There appear to be some differences between true annual marks and accessory marks.

4. There occurs a variation in the appearance of the central area of the centrum that may be a source of trouble in deciding which ring is the first annulus.

5. The correlation found between age of scaled fish determined by the scale method and the age as determined by count of the vertebral marks indicates that the markings on the scales and vertebrae are probably caused by the same variations in growth rate.

6. Evidence for the validity of the vertebral aging method is as follows:

- a. Vertebrae from young-of-the-year bullheads had no or only extremely faint rings.
- b. Vertebrae from bullheads known to be one year old had one heavy, well-defined ring.
- c. Ages determined from vertebrae of fish from populations in which the age range was known to lay within certain limits were within these limits.
- d. A correlation between length and age as determined from the vertebrae was evident.

7. A tentative estimate of the average growth for the northern black bullhead in the waters studied is given.

ACKNOWLEDGEMENTS

The writer wishes to thank Drs. H. M. Harris, Carl Drake, George O. Hendrickson, and Thomas Scott for the interest they have shown in this study. Thanks are due Dr. Kenneth D. Carlander who assisted in both the field and laboratory work and directed the research. Mr. Harland Chandler of Knoxville, Iowa, contributed a great deal to the work by helping to obtain the collections from Marion County. Messrs. Wade Hamor, William Tate, William Starrett, and Robert Cleary helped in making possible the sampling of several different populations. Their suggestions and opinions were of great value. The author is further indebted to Mr. Tate for the smallmouth bass material and to Mr. Cleary for a translation of one of the important German papers. The author also wishes to express his appreciation to Mr. Lowell Johnson and Mr. Van Zomeron, both of Marion County, for permission to seine in ponds on their farms.

LITERATURE CITED

- BÜCKMANN, ADOLF
1929. Methodikfischereibiologischer untersuchungen an Meeresfischen. In Abderhalden, Emil. Handbuch der Biol. Arbeitsmeth. Abt. IX. Methoden der Erforschung der Leistungen des tierischen Organisms. Teir 6, Heft 1, Lief 307. Methoden der Meeresfischereibiologie. s. 120-159 Berlin, Germany, Urban und Schwarzenberg.
- CREASER, CHARLES W.
1926. The structure and growth of the scales of fishes in relation to the interpretation of their life-history, with special reference to the sunfish, *Eupomotis gibbosus*. Mich. Mus. Zool. Misc. Publ. 17:1-83.
- RANEY, EDWARD C., AND DWIGHT A. WEBSTER
1940. The food and growth of the young of the common bullhead, *Ameiurus nebulosus nebulosus* (Le Sueur), in Cayuga Lake, New York. Trans. Amer. Fish. Soc. 69:205-09.
- VAN OOSTEN, JOHN
1929. Life history of the lake herring (*Leucichthys artedi* Le Sueur) of Lake Huron as revealed by its scales with a critique of the scale method. Bull. of U. S. Bur. of Fisheries 44:265-428.

FERMENTATIVE UTILIZATION OF CASSAVA THE PRODUCTION OF ETHANOL

JULIAN BANZON,¹ E. I. FULMER, AND L. A. UNDERKOFER

Department of Chemistry, Iowa State College

Received December 14, 1948

The cassava plant belongs to the family *Euphorbiaceae* and is botanically known as *Manihot utilissima* Pohl. It is also called tapioca or manioc although the term tapioca is more generally used to designate certain forms of cassava products. The plant itself is a perennial shrub which attains a height of six to twelve feet at the age of one year. At the base of its stem it produces a cluster of long fleshy roots as shown in Figures 1 and 2. These cassava roots furnish the cheapest source of starch known. Although its growth is restricted to tropical regions, the cassava is a plant possessing quite unusual characteristics. It has no known pests or enemies; it grows in most soils, resists extreme drouths, and propagates easily.

American technologists who early visited the Philippine Islands were enthusiastic over the cassava. Bacon (3) stated: "It will furnish the cheapest source of starch in the world and also compete on even grounds with molasses for the manufacture of alcohol." Copeland (8) gave an excellent description of the cassava together with its history, varieties, toxicity, culture and uses. In the Philippines the yield of cassava was reported by Mendiola (19) to be 16,100 to 38,300 kg. per hectare (7.18 to 17.3 tons per acre); in Java yields as high as 50,000 to 55,000 kg. per hectare (22.3 to 24.7 tons per acre) have been obtained. The starch content of the fresh cassava root is 25 to 30 per cent. However, in spite of its promise, up to the present no industrial utilization has been made of cassava except for the manufacture of starch. Cassava starch was found in the market throughout the world before the last war, because it could undersell any other starch. In the United States increased production of starches from domestic raw materials has in the past been hampered by this fact.

Fermentative utilization of cassava in the Philippine Islands would be particularly desirable from the standpoint of domestic economy of the Islands. The Philippines are essentially an agricultural country; the commercial production of chemicals by fermentation of cassava would be a step towards industrialization as well as a means of expanding domestic production of liquid fuels. Since petroleum resources are almost absent in the Philippines the importation of liquid fuels, to the

¹ Present address, University of the Philippines, Laguna, Philippine Islands.



FIG. 1.—A cassava plant about 12 months old with a 2-meter stick standing by for comparison of sizes.

value of several million dollars annually, has increased steadily despite the extensive employment of ethanol, either straight or blended, to power tractors, trucks and busses. The ethanol is manufactured from cane molasses, but the entire molasses output of the country if fermented would hardly meet the domestic fuel requirement. The cassava as a potential source of ethanol has been suggested frequently but there



FIG. 2.—Cassava roots from a single plant. A meter stick graduated in centimeters shows relative sizes.

has been no large scale development along this line. It was desirable therefore to investigate thoroughly the possibility of producing ethanol by fermentation of cassava. The work reported in this paper was completed before the outbreak of the war; publication was delayed because of the Japanese invasion of the Philippine Islands. It is of special interest now in connection with Filipino efforts toward rehabilitation of the Islands after the Japanese occupation.

The literature on the fermentation of cassava is very limited. Moore (21) and Lange (17) pointed out its industrial possibilities for the manufacture of glucose and industrial alcohol. Monier-Williams (20), in his monograph on power alcohol, considered cassava as one of the more important raw materials from the point of view of yield and availability. Calculated on the per acre basis, the data of Monier-Williams placed cassava as the highest yielding crop in terms of gallons of alcohol. Collens (7), at the Government Laboratory in Trinidad, conducted a few experiments on the alcoholic fermentation of cassava flour; malt and taka-diastase were employed for saccharification. The only detailed investigation of the alcoholic fermentation of cassava which has been reported is that of Roxas and Manio (23). These workers employed acid hydrolysis of the starch with subsequent yeast fermentation. Yields of over 90 per cent were claimed. The alcoholic fermentation of fresh cassava roots was undertaken by De Leon and Valentin (10). Acid hydrolysis was employed, but the yields were low, the highest obtained being only 43.24 per cent of theory.

MATERIALS AND METHODS

The cassava samples were supplied by the College of Agriculture, University of the Philippines, and were obtained as dried chips from peeled and unpeeled roots; the chips were ground to a coarse powder in a burr mill before use. *Cassava flour* resulted from the grinding of the chips from the peeled roots. One batch analyzed 79.2 per cent starch; another batch analyzed 82.5 per cent starch. The term *ground cassava* is used to designate the material resulting from grinding the chips from the unpeeled roots. Since peeling the roots is a rather laborious operation, the ground cassava represents a very much cheaper material than the cassava flour. As far as is known ground cassava has not been used in the industries or previously studied in the laboratory. Three batches of ground cassava were found to contain 71.2, 76.6 and 74.5 per cent of starch.

All starch analyses were made by the official direct acid hydrolysis method of the A.O.A.C. (2); the reducing substances formed were determined by the method of Shaffer and Hartmann (26). This method was used for all reducing sugar analyses throughout this investigation.

Three materials were employed as sources of amylase. A mold amylase preparation was made according to the method of Underkoffer, Fulmer and Schoene (27) by growing the mold *Aspergillus oryzae* on wheat bran in a rotating drum. The product was air-dried and ground in a Wiley mill and is referred to as mold brand. The amylolytic activity of this mold bran was about one-third that of similar products subsequently produced in the laboratory as well as on the pilot plant and commercial scale by improved methods (28, 29). Barley malt was obtained from the Fleischmann Malting Company, and was ground in a burr mill before use. A sample of the bacterial enzyme product "Rapidase 10X" was secured from the Wallerstein Laboratories.

The malt extract used for the preparation of medium for propagation of the yeast cultures was Blue Ribbon Malt Extract commercially available from the Premier-Pabst Corporation. A 10 per cent solution was employed, and is subsequently designated as beer wort. The yeast culture employed was the same strain of *Saccharomyces cerevisiae* previously employed in work reported from these laboratories (13, 27).

The yields of ethanol obtained were used as the measure of the efficiency of the various experimental treatments. The cassava mash was employed for the tests were prepared, unless otherwise stated, in the following manner: Measured amounts of water were added to weighed quantities of the cassava material in 500-ml. Erlenmeyer flasks. The mixed materials were heated over a burner with constant stirring until gelatinization of the starch had been effected, and the resulting pastes were cooked in an autoclave at 15 pounds steam pressure for 30 minutes unless otherwise stated. The quantities of materials employed, and the times and pressures of cooking when these were varied with the different experiments, are given below in the description of the experimental work. Unless stated otherwise, when amylolytic materials were employed to effect saccharification of the cassava starch, the cooked mash was cooled to the temperature to be employed, the amylolytic materials added, and the temperature maintained for the desired holding time by immersing the flasks in a large constant-temperature water bath. When the saccharifying period was completed the mash was cooled to 30°C. and inoculated from 24-hour cultures of yeast in beer wort, using 5 to 8 ml. of the inoculum per 100 ml. of mash. After incubation for 72 hours at 30°C., the resulting fermented beers were distilled for determination of ethanol yields. All necessary analytical determinations and calculations of results were made in the manner described by Hao, Fulmer and Underkofler (13). Corrections were made, as by these authors, for the ethanol from the inoculum and the saccharifying agents. That is, the measure of the efficiency of the various experimental treatments was the percentage of the theoretical yield of ethanol obtained from the cassava starch alone. The correction values were obtained by differential fermentation of the materials in question. An example, giving average data, is as follows: Fermentation of

4 g. mold bran + 100 ml. beer wort gave 3.11 g. ethanol;
4 g. mold bran + 200 ml. beer wort gave 6.14 g. ethanol;
8 g. mold bran + 200 ml. beer wort gave 6.27 g. ethanol.

Hence, the corrections for beer wort and mold bran were calculated from the data as $6.14 - 3.11 = 3.03$ g. ethanol per 100 ml. of beer wort, and $6.27 - 6.14 = 0.13$ g. ethanol from 4 g. of mold bran or 0.0325 g. ethanol per gram of mold bran. Employing malt instead of mold bran in a similar manner resulted in a correction value for malt of 0.334 g. ethanol per gram of malt.

All the data reported in this paper represent the averages from

experiments run in duplicate or triplicate. A Cameron glass electrode meter was used for measuring pH values.

THE USE OF ACID IN MASHING CASSAVA FOR FERMENTATION

The use of dilute acids for saccharifying starch has long been employed for the production of dextrose; however, the use of acids to convert starchy materials for the ethanol fermentation has never been practiced on the industrial scale. Nevertheless this attractive possibility has occasioned considerable research. Recently ethanol yields comparable with those from amylase saccharified mashers have been secured from acid saccharified grain mashers provided the acid saccharification was supplemented with small amounts of mold bran (24).

The reports of Roxas and Manio (23) and of De Leon and Valentin (10) differed as to the yields of ethanol obtainable from mashers of cassava saccharified with acid. Hence, it was desirable to further investigate this method with cassava.

An extensive series of investigations was conducted. Concentrations of sulfuric acid employed varied between 0.1 N and 0.8 N and the ratios of ground cassava to acid from 1:16 to 1:1. Cooking temperatures were varied from 100° to 130°C. (zero to 25 pounds gauge steam pressure) for periods ranging from 15 to 180 minutes. Space does not permit presentation of the details of these experiments which are given in full in another place (4). However, in all cases the mashers after cooking with the acid were neutralized to pH = 5.0 by means of concentrated ammonium hydroxide, diluted to the same mash concentration of 12 per cent cassava solids and fermented with yeast to determine the alcohol yield obtainable after the treatments employed.

Maximum production of reducing sugars, calculated as dextrose from the Shaffer-Hartmann analyses and amounting to 98.8 per cent of the starch present, was obtained with a cassava to acid ratio of 1:2.5 using 0.4 N acid and heating under 25 pounds steam pressure (130°C.) for 2.5 hours. However, when the mashers prepared in this way were fermented the conversion to alcohol was only 69 per cent of theory. In fact, the conversion of titratable sugars formed by the acid hydrolysis to ethanol by fermentation had no correlation with the quantities of sugars present. This result is in accord with the findings of Severson (25) with corn. The highest yield of ethanol obtained from acid hydrolyzed cassava mashers fermented at 12 per cent concentration was 74.4 per cent of theory, the hydrolysis being conducted with 0.1 N sulfuric acid at a cassava to acid ratio of 1:8, heated at 20 pounds steam pressure (126°C.) for 2 hours. When mold bran to the extent of 5 and 10 per cent of the weight of cassava was added to similar mashers the ethanol yields were 76.4 and 79.2 per cent of theory, respectively. That is, an increase in ethanol yield of about 6 per cent was realized by adding the 10 per cent of mold bran. This amount of the mold bran used would correspond to about 3 or 4 per cent of mold bran of the quality at present available commercially (28, 29).

The effect of adding malt, wheat bran, heat-inactivated mold bran and heat-inactivated malt to acid hydrolyzed cassava mash was investigated. Only the active mold bran markedly increased the alcohol yields which confirms the results of Ruf, Stark, Smith and Allen (24) with acid hydrolyzed grain mash.

THE USE OF AMYLOLYTIC MATERIALS IN MASHING CASSAVA

Mashing may be defined as the process which renders a starchy material ready for alcoholic fermentation. The process may be considered to involve three steps: gelatinization or hydration of the starch, liquefaction of the starch, and saccharification. The final objective is a soluble transformation product which can be readily acted upon by yeast. The function of amylolytic materials employed in the conventional methods of grain mashing is to accomplish the latter two steps, liquefaction and saccharification of the gelatinized starch, through the action of the enzymic complex called "amylase." During the experimental work connected with the acid saccharification of cassava followed by addition of mold bran, it was noted that the most outstanding characteristic of the acid hydrolyzates was the ease of mashing as contrasted with the cassava pastes which had not been acid treated.

The conventional means of saccharifying mash of starchy materials for fermentation by yeast is the use of barley malt. This procedure is not readily applicable to local Philippine conditions since barley is not grown in the Philippines and the importation of malt would be too costly. However, it was desirable for comparative purposes to first investigate the results obtainable by use of this most commonly employed amylolytic material. In the conventional "malting" process the liquefying and saccharifying steps of mashing are combined. The cooked starchy mash is cooled to conversion temperature (usually 60° to 65°C.), actively diastatic barley malt is added and the temperature is maintained for a period to allow the amylase time for liquefaction and saccharification of the starch to fermentable sugars. The saccharified mash is then cooled to pitching temperature and inoculated with yeast. During the war period a flash conversion method was introduced (12), which largely eliminates the holding period.

In two series of cassava fermentations converted by the usual malting methods employing from 2 to 20 per cent of malt, ethanol yields were quite low; the highest yield was obtained with 20 per cent malt and amounted to 69.5 per cent of theory. In another experiment the concentration of the cassava in the mash was varied. The cooked mash was cooled to 60°C., and saccharified at that temperature for one hour. In one series 10 per cent of barley malt, and in another 10 per cent of mold bran were used for the saccharification. The malted mash averaged 72.5 per cent of theory ethanol yield, whereas the mash converted with mold bran averaged 84.6 per cent of theory yield. At the higher mash concentrations considerable difficulty was experienced in mixing the amylolytic agents with the mash, due to the

thick, pasty consistencies. This experiment demonstrated that mold bran gives better results than malt, and that low concentrations of cassava do not present much of a problem in mashing, but the higher concentrations offer difficulties. For industrial use fermentation mashers should be as concentrated as practicable because of resulting economy of size of cookers, fermenters and stills and lowered fuel costs. Cooked cassava pastes of carbohydrate content comparable with those usually employed in the fermentation industry were found to set to almost solid gels on cooling, and the usual mashing operations carried out at 60°C. were found almost impossible to perform. Apparently an irreversible hydration or retrogradation occurred, of the nature pointed out by Beresford and Christensen (5) and by Christensen (6) to be especially bad with root and tuber starches. To overcome or avoid the formation of mashers so thick as to be unworkable the operation known as thinning was given careful study.

The thinning or liquefying step in mashing is the operation in which the starch paste is subjected to the action of hydrolytic agents with the result that the viscosity is markedly lowered. It is not necessary in thinning that the reducing sugar content be materially increased, but the degradation of the starch molecules to dextrins must result in a fluid mash. It has been found that three general procedures for the liquefaction of cassava starch pastes may be followed. The first is the use of acids to reduce the viscosity or thin the starch pastes, the other two involve the use of amylase to accomplish the thinning.

Thinning with Acid

Various concentrations of sulfuric acid and various ratios of ground cassava sample to acid volume were employed to determine conditions necessary for adequate thinning of cassava mashers by acid. For each sample in the series 10 g. of ground cassava were employed, and the concentrations of acid and volumes of acid used were varied. The mixtures were autoclaved for 60 minutes at 20 pounds steam pressure. The thinning was considered to be satisfactory when the product, upon cooling to room temperature, remained somewhat fluid and did not cake to a hard mass. The ratios of weight of sample to acid volume which gave satisfactory thinning were found to be: 1:3 with 0.1 N sulfuric acid, 1:2 with 0.2 N acid, 1:1.5 with 0.4 N acid, and 1:1 with 0.8 N acid. When the mashers prepared under the above conditions were diluted with water to give, in each case, a mash concentration of 16 per cent, the resulting mashers were satisfactory and no hard lumps were found to be present. When lower sample to acid ratios were employed the resulting diluted mashers were thinner than necessary for easy working, and when higher sample to acid ratios were used the resulting diluted mashers contained hard lumps of gelatinized and retrograded starch. While it is thus possible to obtain satisfactory thinning of cassava pastes with sulfuric acid, objections to the use of acid are the necessity of neutralizing the excess acid, and the need for special acid-resistant equipment.

General Methods of Thinning Cassava with Amylolytic Materials

The first of the two thinning procedures which employs amylase involves the liquefaction of the starch *during* the gelatinizing period. In this method the amylase-containing material is mixed with the starchy substrate at room temperature, water is added and the mixture is heated above the gelatinizing temperature. Under this procedure the amylase attacks the starch granules during the process of swelling and hydration and the starch-water mixtures hardly pass through the viscous, gelatinized state at all.

The second of the thinning procedures which makes use of amylase involves liquefaction *after* gelatinization of the starch. In this method the starchy material is mixed with water, gelatinized by heating and cooked under pressure. The temperature of the cooked mash is lowered rapidly to a point near the gelatinizing temperature and the amylolytic material added immediately.

Either of the above outlined procedures is so designed as to avoid carrying out the liquefying operation at temperatures lower than the gelatinizing temperature because the retrograded pastes then encountered are thick, difficult to work with and exceedingly difficult if not impossible to liquefy and saccharify.

Simultaneous Gelatinization and Thinning with Amylolytic Materials

Fermentation studies were first made on mashies liquefied during the gelatinizing period. A large number of experiments were performed in which mold bran and malt were employed. In one experiment a bacterial enzyme preparation, Rapidase 10X, was used. The thinning was accomplished in all cases by mixing the dry amylolytic material with weighed quantities of ground cassava in flasks, adding water, previously heated to 85°C. and containing sufficient sulfuric acid to give a pH of 5.0 in the mixed mashies, and stirring the resulting pastes continuously. The temperature of the mixtures obtained in this manner was a little above 70°C., the approximate gelatinizing temperature for cassava starch. Each of the amylolytic materials employed gave satisfactory thinning under these conditions. The resulting mashies were then cooked in the autoclave, cooled to 60°C., and saccharified at that temperature with malt or mold bran, then cooled to 30°C., inoculated with yeast and fermented. During the course of the investigation, mash concentration, proportions of liquefying agent and saccharifying agent were varied. The details of these numerous experiments are reported in another place (4). Typical results, representing seven different series of experimental fermentations are shown in Table 1.

As a result of this study it was found that mold bran, malt and Rapidase all gave mashies which were thinned sufficiently for satisfactory handling. A mash concentration of 16 per cent cassava was found to be most satisfactory although mashies containing as much as 24 per cent cassava could be handled. With mold bran employed as thinner, using

a total mold bran proportion of 10 per cent of the weight of cassava, 3 per cent of mold bran as thinner with 7 per cent as saccharifying agent gave best ethanol yields. The importance of thinning is demonstrated by the lower yield of ethanol obtained when 9 per cent of mold bran was

TABLE 1
ETHANOL YIELDS FROM MASHES THINNED AND SACCHARIFIED WITH VARIOUS
AMYLOLYTIC MATERIALS

Mash Concentration, g. Ground Cassava per 100 ml.	Thinning Agent, Percentage of Cassava	Saccharifying Agent, Percentage of Cassava	Ethanol Yield, Percentage of Theory
16.....	0	10 malt	67.2
16.....	1 malt	9 malt	67.9
16.....	2 malt	8 malt	64.6
16.....	3 malt	7 malt	67.2
16.....	4 malt	6 malt	66.9
8.....	1 malt	9 malt	65.6
12.....	1 malt	9 malt	70.5
16.....	1 malt	9 malt	74.0
20.....	1 malt	9 malt	73.0
16.....	1 malt	9 malt	73.8
16.....	1 malt	9 mold bran	79.9
16.....	1 mold bran	9 malt	76.1
16.....	1 mold bran	9 mold bran	86.5
8.....	1 mold bran	9 mold bran	83.8
12.....	1 mold bran	9 mold bran	83.8
16.....	1 mold bran	9 mold bran	87.2
20.....	1 mold bran	9 mold bran	82.7
24.....	1 mold bran	9 mold bran	81.8
16.....	2 mold bran	3 mold bran	71.4
16.....	2 mold bran	8 mold bran	82.0
16.....	2 mold bran	10 mold bran	88.8
16.....	2 mold bran	13 mold bran	84.5
16.....	1 mold bran	9 mold bran	73.5
16.....	2 mold bran	8 mold bran	80.3
16.....	3 mold bran	7 mold bran	80.5
16.....	4 mold bran	6 mold bran	76.4
16.....	5 mold bran	5 mold bran	73.9
16.....	0.1 Rapidase	9 malt	75.8
16.....	0.1 Rapidase	9 mold bran	87.2
24.....	0.1 Rapidase	9 mold bran	86.9
30.....	0.1 Rapidase	9 mold bran	83.8

available for saccharifying and 1 per cent for thinning than when 7 per cent was available for saccharifying and 3 per cent for thinning. Mashs saccharified with malt gave characteristically low ethanol yields when thinned with either malt or mold bran. The yield of ethanol was better when mold bran was used as saccharifying agent for mashs thinned with malt, but not as good as from mashs both thinned and

saccharified by mold bran. It was conclusively demonstrated that there is a very great superiority of mold bran over malt for cassava mash, especially as liquefying agent, but also as saccharifier. Mash, thinned with Rapidase gave ethanol yields of the same order as from mash thinned with mold bran, and if available at reasonable cost bacterial enzymes would present a very satisfactory solution to the thinning problem presented by the thick, mucilaginous character of concentrated cassava pastes.

Thinning with Mold Bran after Gelatinization

Since the method of thinning with amylolytic materials before cooking results in destruction of the amylase of the thinner during the cooking, the second method of thinning previously outlined, thinning with amylase after gelatinization, was given close attention. A suspension of mold bran was prepared for use as thinner by vigorously shaking 1.8 g. of mold bran with 100 ml. of distilled water at 40°C. This suspension was used to thin cassava pastes in the following manner: The gelatinized and cooked cassava paste was cooled to about 70°C. and a volume of the mold bran suspension containing a weight of mold bran equivalent to 0.5 per cent of the weight of cassava used was added and the mixture stirred. Liquefaction took place quickly. While this method of thinning was found to be effective it worked best at mash concentrations in the neighborhood of 12 per cent. More concentrated pastes were somewhat more difficult to handle, even when the amount of mold bran employed was increased. The pastes were more workable the higher the temperature, but enzymic activity of the mold bran was destroyed quite rapidly at these higher temperatures.

To determine the proper limits of temperature for thinning by this method 10 ml. of a slurry containing 0.18 g. of mold bran (equivalent to 0.5 per cent of the weight of cassava used) was added to 12 per cent cassava mash at temperatures varying from 85° to 60°C. After a period the mash was cooled to 30°C. and the condition of the mash observed. The results are shown in Table 2. Experience showed that properly thinned mash always separated on standing into an almost water-thin supernatant liquid and a layer of solid sediment. Improperly thinned mash remained as a thick semi-liquid. The retrograded starch in such mash was not saccharified satisfactorily in subsequent steps and gave low ethanol yields. As shown by the data of Table 2 the upper and lower limits for thinning cassava mash by this procedure were 75° and 65°C., respectively.

Since this method of thinning the cooked mash at temperatures above the gelatinizing point gave satisfactory results, the subsequent stages of saccharification and fermentation of such mash were carefully investigated. Preliminary experiments with cooked mash which had been thinned by adding mold bran suspension at about 70°C. indicated that the usual method of saccharification for 60 minutes at 60°C. did

not give satisfactory ethanol yields. Hence, the time and temperature for saccharification and the proportions of mold bran employed were systematically varied. From the preliminary results it became apparent that, using 10 per cent of mold bran based on weight of cassava, the shorter the time the flasks of mash were held at 60°C., or the lower the temperature of the saccharifying bath, the better were the yields of ethanol obtained upon fermenting the mashes. An experiment was devised therefore to study the interrelationships of mold bran concentration, length of time in the saccharifying bath at 60°C., and ethanol yields. The mashes were prepared by making up 24 samples in 500-ml. Erlenmeyer flasks each containing 36 g. of ground cassava gelatinized at 80°C. with 250 ml. of water containing 3 ml. of 2 N sulfuric acid to adjust the pH to 5.0, and cooked at 15 pounds steam pressure for an hour. Upon removal from

TABLE 2
EFFECT OF TEMPERATURE ON THE THINNING OF CASSAVA PASTES WITH MOLD BRAN

Temperature of Cassava Paste, °C.		Time of Standing Before Cooling min.	Liquefaction
Initial	After Adding Mold Bran Suspension		
85.....	83	15	Unsatisfactory
80.....	78.5	15	Unsatisfactory
75.....	74	15	Satisfactory
75.....	74	30	Satisfactory
70.....	69	15	Satisfactory
70.....	69.5	30	Satisfactory
65.....	64.5	15	Satisfactory
65.....	64	30	Satisfactory
60.....	59	15	Unsatisfactory
60.....	59	30	Unsatisfactory

the autoclave the samples were allowed to cool to 70°C., then 10 ml. of 1.8 per cent mold bran suspension were admixed as thinner and the mixtures were allowed to stand for 15 minutes with frequent shaking. Three concentrations of mold bran were employed for the saccharification, 5, 7.5 and 10 per cent of the weight of cassava. The lengths of time in the saccharifying bath at 60°C. were 0, 15, 60 and 120 minutes. After the indicated times the flasks were rapidly cooled to 30°C. and all were inoculated with yeast at the same time. A slight advantage was found for saccharifying at 60°C. for only 15 minutes. With these conditions 7.5 per cent of the mold bran was sufficient to obtain good ethanol yields. The alcohol yields were affected adversely when saccharification was allowed to continue for one or two hours at 60°C.; in fact, better results were obtained when the saccharifying bath was entirely eliminated and the saccharifying mold bran introduced into the cassava mash at 30°C.

These results indicated that proper conditions for saccharification have a decided effect on the alcohol yields. For this reason a more careful study of this process was made. Various temperatures of saccharifying bath and different lengths of time in the bath were investigated. The

method of preparing and thinning the mashers was the same as in the preceding experiment. The proportion of mold bran employed for saccharification was 7.5 per cent of the weight of cassava. The results (Table 3) demonstrate conclusively that extended periods of saccharification at elevated temperatures are not only unnecessary but have a tendency to lower the ethanol yields. Within recent years, subsequent to the completion of the work reported in this paper, a "flash conversion"

TABLE 3
EFFECT OF TIME AND TEMPERATURE OF SACCHARIFICATION WITH MOLD BRAN ON
ETHANOL YIELDS

Temperature of Saccharifying Bath, °C.	Time in the Saccharifying Bath, min.	Ethanol Yield Percentage of Theory
30.....	60	84.7
30.....	120	84.6
40.....	15	84.4
40.....	30	84.0
40.....	60	83.5
40.....	120	81.8
55.....	15	83.2
55.....	30	83.2
55.....	60	81.3
55.....	120	80.6
60.....	15	83.4
60.....	30	80.0
60.....	60	78.3
60.....	120	73.2
65.....	60	64.7
70.....	60	57.5
75.....	1	56.5
75.....	3	57.4
80.....	1	57.2

system involving the elimination of the extended holding time has been introduced into the grain fermentation industry (12).

DISCUSSION AND CONCLUSIONS

From the results obtained in this investigation it may be concluded that ground cassava is a very satisfactory substrate for alcoholic fermentation. Presumably fresh cassava roots would be equally satisfactory. However, suitable procedures for liquefying and saccharifying, differing from conventional malting procedures used for grain fermentations, need to be employed with cassava mashers.

Conventional malting procedures, even when mold bran is substituted for malt, have been found to be impractical with cassava mashers

due to the rapid retrogradation of the cassava starch which renders introduction of the amylolytic material into the mash at malting temperatures very difficult or impossible, and prevents satisfactory saccharification. Liquefaction of cassava mashes by either acid cooking, or use of bacterial or fungal enzymes is satisfactory. Saccharification is best accomplished by means of fungal enzymes. It is interesting in this connection to note that unpublished work in our laboratories on the production of ethanol from sweet potatoes have led to the same conclusions. Yields of ethanol from sweet potatoes saccharified by means of malt were always considerably lower than when mold bran was used as the saccharifying agent. Recently Jump, Zarow and Stark (16) reported that satisfactory yields of alcohol from dehydrated sweet potatoes could not be obtained, with malt as the saccharifying agent, unless accessory materials were added. In a continuation of this work Hao and Stark (15) found that by the use of fungal amylases as sole conversion agents or in combination with reduced percentages of barley malt, maximum yield and efficiency were obtained with dehydrated sweet potatoes.

Acid cooking of cassava mashes results in hydrolysis of the starch, but in order to produce good yields of ethanol from the acid hydrolyzed mashes, mold bran must be added. The physical condition of the mash resulting from the acid cook is of much more importance than the degree of saccharification resulting from the action of the acid.

Bacterial enzymes such as Rapidase are useful for thinning cassava mashes. Since such enzymes produce only liquefaction without marked saccharification and are active at temperatures up to 90°C., they are most conveniently employed by adding them to the cassava, then mixing with hot water to produce simultaneous gelatinization and liquefaction. A similar method of liquefaction may be employed using mold bran.

The most satisfactory method of thinning with mold bran was found to be stirring the freshly cooked cassava paste at about the gelatinizing temperature of the starch with a suspension of mold bran in water. Temperatures between 65° and 75°C. are satisfactory, where the cassava paste is sufficiently fluid for easy mixing and the temperature is not so high as to destroy the amylase too rapidly. The more quickly the cooked mash is cooled to liquefying temperature, the less likely it is that retrogradation will occur and render more difficult the liquefaction and saccharification of the starch.

In the thinning process the chemical change brought about by fungal or bacterial amylases is believed to differ from that produced by malt because, although each of these three amylolytic agents is able to reduce the viscosity of cassava mashes to about the same degree, the ethanol yields vary according to whether malt or the microbial products is employed as thinning agent. It is well known that the amylase system of malt differs markedly from those from fungal or bacterial sources. The primary conversion products (dextrins) produced by thinning with mold bran or bacterial amylase appear to be much more readily saccharified by the amylases of either malt or mold bran, although the latter gives better

results, than the dextrins produced by thinning with malt. An advantage has been demonstrated repeatedly for fungal amylases over malt amylase as regards final ethanol yields from other starchy materials (13, 14, 15, 22, 29). Corman and Langlykke (9) have shown that the "glucogenic activity" of fungal enzyme preparations has a very important influence on the final alcohol yields. Undoubtedly the presence of this factor in mold bran and its absence in malt is a major reason for the superiority of mold bran to malt for saccharifying starchy mashers for yeast fermentation.

The best procedure for the mashing of cassava, based upon the results of this investigation, is as follows: A gelatinized cassava paste is prepared containing 12 to 20 g. of cassava dry solids per 100 ml. of water by heating under pressure with continuous agitation. The freshly cooked paste is cooled as rapidly as possible to about 70°C. and liquefied by adding with stirring a suspension of 5 to 10 per cent of the total mold bran to be employed. While the total requirement for the mold bran employed in the present investigation was about 8 per cent of the weight of cassava used, for mold brans with the potency currently produced (28, 29) about 3 to 4 per cent is the optimum amount. After the mash is satisfactorily thinned, it is cooled to 30°-40°C. and a quantity of mold bran introduced sufficient to produce maximum saccharification. The mash is then inoculated with yeast, fermented and distilled in accordance with usual practice.

The above procedure is readily adaptable to industrial scale operations employing equipment generally used in alcohol plants for grain fermentations. Mold bran, which has been demonstrated on the industrial scale to be satisfactory for grain fermentations (28, 29) is recommended for saccharifying cassava mashers. Amylase preparations produced by submerged cultivation of suitable molds in liquid media (1, 11, 18), have been shown on the pilot plant scale to be useful in grain fermentations, and may be expected to prove equally satisfactory for cassava fermentation. However, methods for the preparation and use of submerged fungal preparations have not yet been conclusively proven on the full industrial scale.

LITERATURE CITED

1. ADAMS, S. L., B. BALANKURA, A. A. ANDREASEN, AND W. H. STARK
1947. Submerged culture of fungal amylase. *Ind. Eng. Chem.* 39:1615-17.
2. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS
1940. *Methods of analysis*, 5th ed.
3. BACON, R. F.
1908. Starch production in the Philippines. *Philippine Jour. Sci.* 3A:93-98.
4. BANZON, J.
1940. Fermentative utilization of cassava. Ph.D. thesis, Iowa State College Library.
5. BERESFORD, H., AND L. M. CHRISTENSEN
1941. The production of ethyl alcohol from cull potatoes and other farm crops. *Idaho Agr. Expt. Sta. Bull.* No. 241.

6. CHRISTENSEN, L. M.
1943. Efficiency of the production of ethanol from starchy substrates. *Cereal Chem.* 20:478-82.
7. COLLENS, A. E.
1914. Alcohol from cassava. *Dept. Agr. Trinidad and Tobago, Bull.* 14:56.
8. COPELAND, E. E.
1908. Manioc or cassava. *Philippine Agr. Rev.* 1:139-56.
9. CORMAN, J., AND A. F. LANGLYKKE
1948. Action of mold enzymes in starch saccharification. *Cereal Chem.* 25:190-201.
10. DE LEON, A. I., AND I. VALENTIN
1938. College of Agriculture, University of the Philippines, private communication.
11. ERE, N. M., AND F. M. HILDEBRANDT
1946. Mold as an adjunct to malt in grain fermentation. *Ind. Eng. Chem.* 38:792-94.
12. GALLAGHER, F. H., H. R. BILFORD, W. H. STARK, AND P. J. KOLACHOV
1942. Fast conversion of distillery mash. *Ind. Eng. Chem.* 34:1395-97.
13. HAO, L. C., E. I. FULMER AND L. A. UNDERKOFER
1943. Fungal amylases as saccharifying agents in the alcoholic fermentation of corn. *Ind. Eng. Chem.* 35:814-18.
14. ———, AND J. A. JUMP
1945. Microbial amylase preparations conversion agents for alcoholic fermentation. *Ind. Eng. Chem.* 37:521-25.
15. ———, AND W. H. STARK
1946. Yield factors in alcohol production from dehydrated sweet potatoes. Paper presented at meeting of American Chemical Society, Atlantic City, N. J.
16. JUMP, J. A., A. I. ZAROW, AND W. H. STARK
1944. Dehydrated sweet potatoes for ethanol production. *Ind. Eng. Chem.* 36:1138-42.
17. LANGE, H.
1909. Die Verarbeitung von Manioka auf Spiritus und Heffe. *Zeit. für Spiritusindustrie* 32:200-1.
18. LEMENSE, E. H., J. CORMAN, J. M. VAN LANEN, AND A. F. LANGLYKKE
1947. Production of mold amylases in submerged culture. *Jour. Bact.* 54(2):149-59.
19. MENDIOLA, N. B.
1931. Cassava growing and cassava starch manufacture. *Philippine Agr.* 20:447-76.
20. MONIER-WILLIAMS, G. W.
1922. Power alcohol, its production and utilization. Henry Frowde and Hodder & Stoughton, London.
21. MOORE, C. C.
1911. Alcohol from cassava. U. S. Patent 977,465.
22. ROBERTS, M., S. LAUFER, E. D. STEWART, AND L. T. SALATAN
1944. Saccharification of wheat by fungal amylases for alcohol production. *Ind. Eng. Chem.* 36:811-12.
23. ROXAS, M. L., AND R. V. MANIO
1921. Industrial alcohol from cassava. *Philippine Agr.* 10:75-84.

24. RUF, E. W., W. H. STARK, L. A. SMITH, AND E. E. ALLEN
1948. Alcoholic fermentation of acid hydrolyzed grain mash continuous process. *Ind. Eng. Chem.* 40:1154-58.
25. SEVERSON, G.
1937. Alcohol yields from acid saccharified cereals. *Iowa State Coll. Jour. Sci.* 11:215-20.
26. SHAFFER, P. A., AND A. F. HARTMANN
1921. Method of determination of reducing sugar in blood, urine, milk, and other solutions. *Jour. Biol. Chem.* 45:365-90.
27. UNDERKOFER, L. A., E. I. FULMER, AND L. SCHOENE
1939. Saccharification of starchy grain mash for the alcoholic fermentation industry. Use of mold amylase. *Ind. Eng. Chem.* 31:734-38.
28. ———, G. M. SEVERSON, AND K. J. GOERING
1946. Saccharification of grain mash for alcoholic fermentation. Plant-scale use of mold amylase. *Ind. Eng. Chem.* 38:980-85.
29. ———, ———, ———, AND L. M. CHRISTENSEN
1947. Commercial production and use of mold bran. *Cereal Chem.* 24:1-22.

THE POST-CRISIS IN BLOOD-INDUCED *PLASMODIUM* *LOPHURAE* INFECTIONS IN WHITE PEKIN DUCKS¹

ELERY R. BECKER, CHARLES E. BRODINE, AND BONNIE L. CLAPPISON

Department of Zoology and Entomology, Iowa State College

Received January 31, 1949

Coggeshall (1938) discovered *Plasmodium lophurae* in the blood of a Borneo fireback pheasant (*Lophura igniti igniti*) kept in the New York Zoological Park. Descriptions and colored plates of the blood stages have been published by Coggeshall (1938) and Hewitt (1942), and of the preërythrocytic developmental stages by Huff, Coulston, Laird, and Porter (1947). Coggeshall found that young chicks of several breeds were quite susceptible to infection by blood-inoculation, but older chickens, though still susceptible, exhibited strong age-resistance. Terzian (1941, 1941a) has made a careful study of biological characteristics and host-parasite relationships of the parasite in chickens, and Hewitt (1942) and Hewitt, Richardson, and Seager (1942) have made comparable studies in ducks. It has been stated that exoerythrocytic forms (= Huff's phanerozoites) other than the preërythrocytic forms previously mentioned do not occur in blood-induced infections (Terzian, 1941, and Taliaferro and Taliaferro, 1945). Although the asexual cycle exhibits but a low degree of synchronicity, it has been possible for Terzian (1941) to estimate the length of the cycle in chickens at forty-eight hours, and for Hewitt (1942) to estimate it in ducks at thirty-six hours. Of domesticated birds, chickens, ducks, pheasants, turkeys, and guinea fowl are susceptible in varying degrees to sporozoite- and blood-induced infection (Huff *et al.*, 1947); and of the caged birds, canaries and zebra finches (Taliaferro and Taliaferro, 1945).

Since our present interest concerns the blood-induced infection in ducks, it is to be pointed out that Wolfson (1940, 1941) first noted the high susceptibility of these birds as evidenced by high and often fatal parasitemias. As has been reported by a number of workers and as we also have found, parasitemias induced in young ducks by moderately heavy intravenous injections of parasitized cells (such as, 1.5×10^6 /kg.) tend to reach the peak on the fifth or sixth day, then decline precipitously for two or three days, and less precipitously for another two or three days. Young untreated ducks succumb within three weeks to this primary attack in 90-95 per cent of the cases (Marshall, Litchfield, and White, 1942).

¹ This investigation was supported in part by Research Grant 675 (C) from the Division of Research Grants and Fellowships of the National Institute of Health, U. S. Public Health Service.

Hewitt, Richardson, and Seager (1942) testify as follows regarding post-crisis developments: "Birds of two and four weeks of age usually develop chronic infections, and if they survive the parasite peak, parasites can be found in the blood for two and three weeks after inoculation. In older birds, however, the parasites disappear more quickly from the peripheral blood if the peak is passed and death does not occur." The statement implies the eventual development of post-crisis latency in ducks. Terzian, noting that parasites disappeared from the blood of chicks after the crisis, declared that in such cases subinoculations into clean birds failed to produce infection. Taliaferro and Taliaferro (1940), however, found that, although the parasites disappear from the blood of chicks in a few days after the crisis, the infection really becomes latent because parasites can be demonstrated in young chicks after injection with relatively large quantities of blood from the recovered birds.

MATERIALS AND METHODS

The strain of *P. lophurae* employed was from an infected duck supplied in September, 1947, by Dr. William Trager of the Rockefeller Institute of Princeton, New Jersey. Since that time the parasite has been transmitted serially through ducklings by intravenous injection of moderately heavy doses of parasitized cells at intervals of four, five, or six days. The host was the White Pekin duck. The ducklings arrived in the laboratory one or two days after hatching, were fed a commercial chick starting ration, and were inoculated at the age of twelve to fourteen days. Each duckling was inoculated with about 2×10^8 parasitized duck cells. Blood smears were fixed in methyl alcohol and stained in Giemsa. Some of the ducklings under observation were untreated, while the others received enough quinine during the first six days of the infection to affect the parasitemia. The counting procedure was the same as that previously employed (Becker, 1949). Ten thousand red cells constituted the minimum counted before a smear was recorded negative.

During the last sixteen months the courses of several hundred infections of *P. lophurae* in ducks have been followed throughout or in part, but the observations on only twenty-six survivors of four series were selected for reporting because there were more survivors in these series than in the others, and the recorded observations on them were the most extensive. Eight of the twenty-six were untreated or control birds, and were the survivors of a total of twenty-five originally inoculated. The other eighteen ducks had received small doses of quinine (7-12 mg./kg. b.i.d.) on each of the first six days of the infection, and comprised the survivors of an original thirty. Incidentally, the Chi-square test shows a significant difference in the mortality of the two groups. Only birds surviving forty-five days after inoculation were included in the present study because of the emphasis on develop-

ments in continuing infections. It is believed by us that there is ordinarily little or no difference in the courses of the untreated and treated infections after the first three weeks.

RESULTS

The percentages of parasitized cells in blood smears made on selected days from each of the twenty-six ducks under observation are recorded in Tables 1-4. The last notation for a particular bird preceded its death by a matter of hours in some cases, in other cases a day or two, except for duck No. 5 which still survives. Ducks Nos. 9, 18, 19, 20, 21, 23, and 24 were sacrificed for use in other experiments, but the remaining eighteen died naturally. The parasitized cell counts preceding death indicated that Nos. 4, 6, 7, 8, 11, 16, and 25 probably died of the malaria, but the cause of death in the other eleven cases was uncertain. Most of these ducks did not grow as well as their mates. Some sickened a day or two before they died. (Authors' note: Duck No. 5, a male, died of leucosis at the age of 368 days, still harboring demonstrable parasites in his blood.)

Microscopically demonstrable parasites recurred after the third week in all twenty-six hosts except No. 19. In order to test the immunity of this bird after ninety days, it was injected intravenously with 4 cc. of duck blood from a five-day infection with 70 per cent of the erythrocytes parasitized. A smear made of its blood a few minutes after the injection contained numerous parasitized cells, but not a parasitized cell could be found in a smear made after twenty-two hours or later. This infection is designated Type 1.

Although the opportunity of testing the infectiousness of the blood of duck No. 19 to young ducklings was passed over, there was under observation at the time another duck with a long history of latency on which the test could be made. The primary infection following inoculation at the age of thirteen days was relatively light, with the peak 27 million parasitized cells on the fourth day and the blood apparently parasite-free on the ninth day. Frequent and thorough examination of stained smears through the 190th day have failed to disclose the persistence of parasitemia. On the 169th day one cc. of whole blood from this duck was injected intravenously into each of two young ducklings. Both birds had 0.36 per cent parasitized erythrocytes on the twelfth day and 5 per cent on the fifteenth day. This demonstrated that a duck with a long record of negative blood smears may harbor, nevertheless, a residue of *Plasmodium lophurae*.

An inspection of Tables 1-4 led to the suggestion that the other twenty-five infections could, for simplification, be classified roughly under three types according to the courses they followed. First there are those of Type 2, in which the parasites seemed to have disappeared from the blood after the crisis and reappeared but sparsely after extended periods of seeming latency. Ducks Nos. 18, 21, and 24 harbored

TABLE 1
PERCENTAGES OF PARASITIZED CELLS IN INFECTED DUCKS OF SERIES 1
(+ indicates 0.05 per cent or less; C = untreated control; Q = quinine recipient)

Day of Infection	Duck Number					
	1(C)	2(C)	3(C)	4(C)	5(Q)	6(Q)
2.....	2.5	4.6	5.0	5.2	1.4	4.0
3.....	17.3	24.5	21.5	23.0	1.2	18.5
3.....	24.5	55.5	64.0	49.0	1.3	19.5
4.....	75.0	84.0	79.0	73.5	0.9	55.0
5.....	70.3	70.0	43.0	59.5	0.3	52.5
6.....	52.0	46.5	26.0	33.5	0.3	54.5
7.....	13.0	64.5	1.7	68.5	0.7	4.1
9.....	0.7	33.0	0.1	49.5	+	0.8
11.....	0.1	11.2	0.4	30.5	0.2	+
14.....	7.8	+	0.1	28.5	0.4	1.0
20.....	0.2	0.6	0.2	12.5	+	0.3
25.....	0.1	0.1	0.2	0.2	0.2	+
30.....	0.2	0.4	0.1	0.2	0.3	0.1
34.....	+	+	0.1	+	+	+
39.....	0.1	0.2	0.1	+	0.1	0.1
54.....	0.2	0.1	0.1	0.5	+	0.7
69.....	0.0	+	+	+	0.0	0.0
78.....	+	+	+	0.0	+	0.0
85.....	0.0	0.0	0.0	0.2	0.0	+
92.....	+	0.0	0.0	19.8	+	0.0
96.....	+	0.0	0.2	.....	0.0	+
106.....	0.0	0.0	+	.....	+	+
113.....	0.0	0.1	0.0	.....	+	0.1
118.....	0.0	0.0	+	.....	0.1	+
124.....	+	0.1	+	.....	+	0.0
130.....	+	.....	0.1	.....	+	+
136.....	+	.....	0.0	.....	0.0	0.0
142.....	0.0	.....	0.0	.....	+	0.0
148.....	0.0	.....	0.0	.....	0.0	0.0
163.....	0.0	.....	0.0	.....	+	+
166.....	0.0	.....	0.0	.....	0.0	0.0
169.....	0.0	.....	0.1	.....	0.0	0.0
172.....	0.2	.....	0.0	.....	0.0	0.0
177.....	+	.....	0.0	.....	+	+
180.....	+	.....	0.0	.....	0.0	0.4
185.....	0.1	.....	.....	.....	0.1	.....
206.....	2.0	.....	.....	.....	0.0	.....
235.....	0.1	.....	.....	.....	+	.....
253.....	+	.....	.....	.....	+	.....
258.....	.....	.....	.....	.....	+	.....
275.....	.....	.....	.....	.....	0.0	.....
278.....	.....	.....	.....	.....	0.0	.....
284.....	.....	.....	.....	.....	0.0	.....
288.....	.....	.....	.....	.....	0.0	.....
301.....	.....	.....	.....	.....	+	.....
304.....	.....	.....	.....	.....	+	.....
306.....	.....	.....	.....	.....	+	.....
312.....	.....	.....	.....	.....	+	.....
336.....	.....	.....	.....	.....	0.1	.....
339.....	.....	.....	.....	.....	+	.....
344.....	.....	.....	.....	.....	+	.....
359.....	.....	.....	.....	.....	+	.....

infections which ran such a course. Those of Type 3 underwent frank recrudescences with mounting parasite counts. Relapses of this type occurred in ducks Nos. 4, 8, 9, 11, 13, 22, 23, and 25, a total of eight, though the peaks of the parasitemias varied considerably in intensity. The Type 4 infections were characterized by comparatively low parasitemias irregularly interrupted by sub-patent periods. Most of the infections, a total of fourteen, were of this type, and included ducks Nos. 1, 2, 3, 5, 6, 7, 10, 12, 14, 15, 16, 17, 20, and 26.

The Type 1 infection in duck No. 19 could be described as the

TABLE 2
PERCENTAGES OF PARASITIZED CELLS IN INFECTED DUCKS OF SERIES 2
(+ indicates 0.05 per cent or less; Q = quinine recipient)

Day of Infection	Duck Number				
	7(Q)	8(Q)	9(Q)	10(Q)	11(Q)
4.....	1.2	2.2	0.8	0.3	2.1
5.....	0.7	3.3	0.5	0.3	1.8
6.....	0.4	1.3	0.1	0.2	1.3
7.....	0.5	1.2	0.4	0.1	1.2
8.....	0.3	1.0	0.3	0.2	0.7
10.....	+	0.1	0.1	0.2	+
13.....	0.0	0.1	+	+	+
16.....	0.0	0.1	+	+	0.1
19.....	+	0.5	0.1	+	0.1
22.....	+	3.4	2.3	0.3	0.0
25.....	0.2	45.0	12.0	1.9	0.2
28.....	+	47.0	35.0	0.2	+
31.....	0.1	2.5	13.8	0.2	+
34.....	+	2.4	0.1	+	0.7
37.....	0.0	3.6	0.1	+	5.4
40.....	0.0	3.6	+	0.1	33.0
43.....	+	1.5	0.0	0.1	57.0
46.....	0.0	+	0.0	0.0	1.7
49.....	0.0	0.0	0.0	0.1	0.3
52.....	0.0	+	0.0	0.3	0.0
55.....	0.0	0.3	0.0	0.0	5.1
62.....	0.0	87.0	0.0	.....	0.0
67.....	0.0	.....	0.0	.....	0.0
74.....	0.1	.....	0.0	.....	+
80.....	0.0	.....	0.0	.....	+
86.....	0.0	.....	0.0	.....	0.0
92.....	0.7	.....	0.0	.....	+
98.....	.....	.....	0.7	.....	0.0
101.....	.....	.....	0.7	.....	0.0
102.....	.....	.....	1.5	.....	+
103.....	.....	.....	1.8	.....	+
104.....	.....	.....	3.1	.....	+
105.....	.....	.....	2.5	.....	+
106.....	.....	.....	2.8	.....	+
107.....	.....	.....	1.3	.....	+
108.....	.....	.....	0.7	.....	+
120.....	.....	.....	0.4	.....	21.0
123.....	.....	.....	0.1	.....	.....
126.....	.....	.....	0.0	.....	.....
128.....	.....	.....	+	.....	.....

latent type; Type 2 infections as sub-latent, *i.e.*, the parasites recur infrequently and in very low intensity. That in Duck No. 18 is a good example. Type 3 infections, in which marked recrudescences of parasite growth occur at intervals, could be described as the recrudescent type. Figure 1 depicts graphically the courses of such infections in a control duck (No. 25) and a duck treated with quinine for the first six days including day of injection (No. 8). Each exhibited ideal infections of this type with two severe post-crisis relapses. The Type

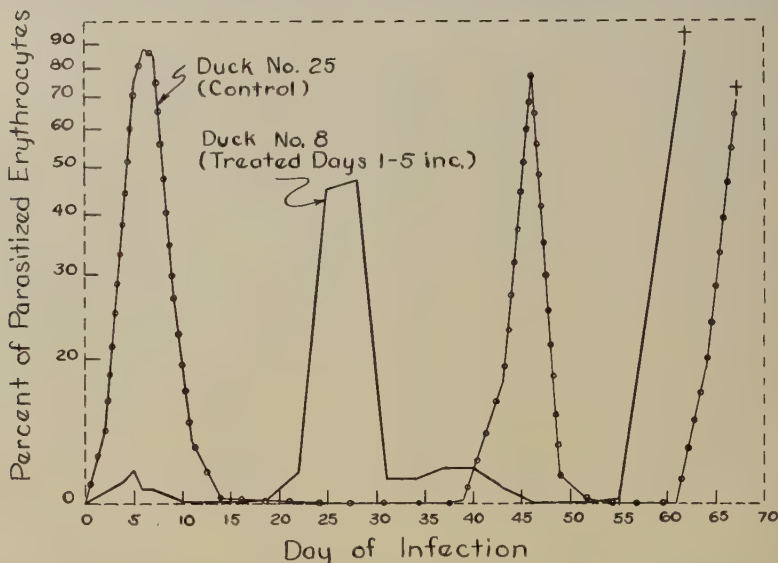


FIG. 1.—The course of the parasitemia in infections of the recrudescent type in duck No. 25, a control, and in duck No. 8, quinine-treated on days 1-5 of the infection. (Note the distortion of the ordinate to shorten it).

4 infection, of which duck No. 5 may be considered the most nearly ideal, is the hardest to describe in a single word, but since the parasites are present frequently and in comparatively low intensities, it will be designated the intermittent type. There are, of course, no hard and fast lines separating the four types. Duck No. 26, for example, listed above as harboring a Type 4 infection, could as correctly have been assigned to Type 2. It is of interest that of the twenty-six ducks under observation one, or 3.8 per cent, harbored Type 1 infections; three, or 11.5 per cent, Type 2 infections; eight, or 30.8 per cent, Type 3 infections; and fourteen, or 53.8 per cent, Type 4 infections.

DISCUSSION

The data which have been presented prove that latency is by no means the universal state of blood-induced *P. lophurae* infection

generated in ducks by the immunization process set off at the crisis. In only one of twenty-six ducks were the parasites not found to recur. These recurrences varied in intensity from considerably less than 0.05 per cent of parasitized erythrocytes to as many as 87 per cent. It was possible to group the post-crisis infections roughly into four types according to the quantitative characteristics of the courses they assumed. Since none of the birds underwent any special treatment after the first six days it is the logical assumption that these four general types were an expression of the variability of both the innate capacities of ducks to cope with the parasite and of the pattern of resistance against the parasite. This variability in capacity to develop resistance to the parasite actually was manifested much earlier, for the twenty-six ducks

TABLE 3
PERCENTAGES OF PARASITIZED CELLS IN INFECTED DUCKS OF SERIES 3
(+ indicates 0.05 per cent or less; C=untreated control; Q=quinine recipient)

Day of Infection	Duck Number			
	12(Q)	13(Q)	14(Q)	15(C)
3.....	2.6	5.6	2.0	16.3
4.....	2.5	3.5	1.2	60.5
5.....	2.0	2.4	1.3	67.0
6.....	1.9	1.7	1.0	70.5
7.....	1.4	1.0	0.7	63.0
9.....	0.1	0.2	0.2	58.0
11.....	0.2	0.1	0.1	33.4
13.....	1.1	0.8	0.9	8.8
16.....	4.6	4.8	1.6	0.2
19.....	0.7	40.5	14.3	0.2
22.....	0.1	0.4	2.1	0.3
25.....	+	0.0	0.2	0.0
28.....	+	+	+	+
31.....	0.0	+	+	0.0
34.....	0.0	+	+	0.0
37.....	0.0	0.0	0.0	0.0
40.....	0.0	0.0	0.0	0.0
43.....	+	0.0	0.0	+
51.....	+	0.0	0.0	+
58.....	+	0.0	+	0.0
63.....		0.0	+	+
69.....		0.0	0.2	+
72.....		0.0	0.0	0.0
78.....		0.0	0.0	0.0
84.....		+	+	
87.....		0.5		
88.....		1.1		
89.....		1.0		
90.....		2.4		
91.....		6.2		
92.....		14.0		
93.....		14.3		
94.....		10.8		
107.....		0.0		
110.....		0.0		
115.....		0.0		

under consideration constituted the survivors of an original fifty-five, over half of which succumbed before the studies had been under way forty-five days. It should be reemphasized that mortality in these four series was unusually low, especially in the control or untreated ducks. In certain other series of ducks a mortality of 90 or even 100 per cent has been encountered in the controls, and as high as 80 per cent

TABLE 4
PERCENTAGES OF PARASITIZED CELLS IN INFECTED DUCKS OF SERIES 4
(+ indicates 0.05 per cent or less; C=untreated control; Q=quinine recipient)

Day of Infection	Duck Number										
	16(Q)	17(Q)	18(Q)	19(Q)	20(Q)	21(Q)	22(Q)	23(Q)	24(C)	25(C)	26(C)
2.....	2.9	1.1	2.1	1.1	2.5	0.8	1.0	1.3	6.0	8.0	8.0
4.....	6.0	0.7	2.0	2.6	4.1	0.4	1.2	1.2	49.0	47.0	54.5
5.....	4.0	0.3	0.9	2.9	2.3	0.1	0.8	0.6	67.0	75.0	78.7
6.....	3.9	0.6	1.5	1.8	2.6	0.3	0.7	0.8	88.0	87.5	88.5
7.....	2.1	0.3	0.8	1.3	1.6	0.2	1.1	0.4	86.5	85.5	85.0
9.....	0.3	+	+	0.1	0.4	0.1	0.4	0.1	48.5	28.0	71.5
11.....	0.2	+	+	+	0.5	+	0.4	+	28.0	6.8	44.5
14.....	1.5	0.1	0.2	+	7.8	0.8	0.8	0.1	5.2	0.4	16.5
21.....	16.5	1.8	0.2	0.0	42.0	12.4	3.9	+	37.0	0.1	18.0
28.....	+	+	0.0	0.0	0.0	+	0.0	7.1	3.8	0.0	+
33.....	0.1	+	0.0	0.0	+	0.0	0.0	20.5	+	0.0	0.0
37.....	+	+	0.0	0.0	+	0.0	+	1.4	0.0	+	0.0
39.....	+	+	0.0	0.0	0.0	+	0.0	0.1	0.1	0.2	0.1
43.....	0.6	+	0.0	0.0	0.2	0.0	0.0	+	+	15.5	+
46.....	+	0.0	0.0	0.0	+	0.0	+	0.0	+	77.0	+
49.....	+	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	2.8	+
52.....	0.1	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.1	+
58.....	0.1	+	+	0.0	+	0.0	1.6	8.7	0.0	+	0.0
61.....	+	0.0	+	0.0	+	0.0	9.3	7.3	0.0	+	0.0
64.....	0.2	0.0	0.1	0.0	+	+	0.1	0.6	0.0	18.3	0.0
67.....	+	0.0	0.0	0.0	0.4	0.0	.....	0.1	0.0	68.5	0.0
78.....	.....	.....	0.1	0.0	.....	.....	.....	.....	0.0	.....	.....
81.....	.....	.....	0.0	0.0	.....	.....	.....	.....	0.0	.....	.....
84.....	.....	.....	0.0	0.0	.....	.....	.....	.....	0.0	.....	.....
87.....	.....	.....	0.0	0.0	.....	.....	.....	.....	0.0	.....	.....
90.....	.....	.....	0.0	0.0	.....	.....	.....	.....	0.1	.....	.....
91.....	.....	.....	0.1	.....	.....	.....	.....	.....	0.2	.....	.....
94.....	.....	.....	0.0	.....	.....	.....	.....	.....	0.0	.....	.....
100.....	.....	.....	0.0	.....	.....	.....	.....	.....	0.0	.....	.....
121.....	.....	.....	0.0	.....	.....	.....	.....	.....	.....	.....	.....

mortality in groups which received quinine, with the dosage 8 mg./kg. *b.i.d.*

The question arises, was the blood actually parasite-free on those days when not a parasitized cell was present in 10,000 counted? The answer is definitely negative in certain cases. For example, duck No. 5 was recorded as negative on the 235th, 253rd, 258th, and 275th days. No parasites were observed by the senior author in 100,000 erythrocytes counted by fields of an estimated 100 in the smear made on the 235th day, but one undeniable parasite was seen in each of the other three smears before 50,000 marks were reached. On the other hand, no

amount of searching resulted in locating parasites in smears from duck No. 19 after the fourteenth day. Then there were ducks, such as Nos. 9 and 24, which were negative over forty-nine- and thirty-eight-day periods, respectively, but afterwards became positive again. It is possible, of course, that the blood was positive on certain days when examinations were not made, but it is unlikely that the parasitemias reached any considerable degree of intensity.

The method of subinoculating young uninfected ducklings with considerable quantities of blood from a microscopically negative duck was not employed as much as it should have been. One notable test was made with ducks Nos. 1, 3, 5, and 6 on the 163rd day, when their bloods appeared to be negative. One cc. of heparinized blood from each was injected into ducklings, resulting in infection in all but the one injected from duck No. 1. The writers were remiss in not making similar tests with the blood from duck No. 19, but as stated above, another duck with a similar record was proved still to harbor parasites by transfusing young ducklings, and a heavy intravenous inoculation of parasitized cells into duck No. 19 was quickly cleared from the blood. Since it is fairly well established that acquired host-resistance to a species or strain of malarial parasite is a premunition, it may be assumed that this bird still harbored a residue of parasites. This assumption, however, may not be safe in all cases, for Gingrich (1948) has reported that canaries cured of *P. cathemerium* with certain anti-malarial drugs retain measurable resistance to reinoculation through the sixth month after treatment, but measurable acquired immunity is lost after eight months. Certain experimenters to whom he refers had previously reported a year's duration of immunity to *P. knowlesi* in monkeys after curative treatment of the host.

It is presumed that exoerythrocytic stages do not occur in ducks with blood-induced infections of *P. lophurae* (v.s.). Consequently, the presence of parasites in the blood at any time is to be ascribed to persisting parasites passing through the ordinary schizogonic cycle in red cells. Their intensity, however, becomes so low at times that they can be demonstrated only after a long search with the microscope, or even only by blood inoculation into susceptible ducklings.

The amazing pathogenicity of the parasite in blood-induced infections deserves special comment. At present writing (339th day) only one duck survives of the forty-eight which were given a chance (seven of the original fifty-five were sacrificed). As was previously stated, twenty-nine (52.7 per cent) of the original fifty-five ducks died before the forty-fifth day of the infection, and this mortality was considerably lower than ordinarily occurs. A number of the birds died with no or very few parasites demonstrable in the circulating blood. Some of the ducks made poor growth gains after the crisis. The failure of infected ducks with low parasitemias to do well poses the problem of the cause. Manwell (1943) has commented on poor condition and unexpected deaths in his ducks infected with a number of other

species of the avian malarias, even though the parasite counts were very low.

The only information available about sporozoite-induced infection in ducks, in papers by Laird (1941), Hurlburt and Hewitt (1942), Jeffery (1944), and the unpublished data of Porter and Laird, quoted by Huff, Coulston, Laird, and Porter (1947) is to the effect that low-grade, irregular infections generally develop in both chicks and ducklings inoculated with large doses of *P. lophurae* sporozoites. Jeffery observed patent periods of forty days and generally low-grade parasitemias, but in three ducks the parasitemia became high. No mention was made of host-morbidity or mortality.

SUMMARY AND CONCLUSIONS

In order to study the quantitative character of prolonged infections, microscopic examinations were made at intervals of the blood of ducks infected with *Plasmodium lophurae* which survived a minimum of forty-five days. It was found that only one infection out of twenty-six studied became permanently latent after the reduced parasitemia following the crisis had run its course. The post-crisis infection ordinarily pursues a "relapsing" course with sub-patent periods of varying length alternating with patent periods also of varying length and with parasitemias of varying intensity. It has been possible to divide the post-crisis infections into four types, as follows in the order of their frequency: (1) the latent, apparently the rarest; (2) the sub-latent, in which the recurrences of the parasite are infrequent and of low intensity; (3) the recrudescent, in which certain of the recurrences of the parasite are of high, or at least comparatively high, intensity; (4) the intermittent, in which patent and sub-patent intervals occur frequently and irregularly, and the parasitemias are of comparatively low intensity.

The high mortality occurring early in blood-induced *P. lophurae* infection when parasitemia becomes high and, among the survivors, in the weeks and months after the crisis when parasitemia is irregular and variable in intensity attests to the susceptibility of ducks to this parasite, as contrasted with the tolerance manifested to it by chickens.

LITERATURE CITED

- BECKER, E. R.
1949. Report on thirty-five drugs and three plant materials tested against *Plasmodium lophurae* in the White Pekin duck. Iowa State College Jour. Sci. 23:189-94.
- COGGESHALL, L. T.
1938. *Plasmodium lophurae*, a new species of malaria parasite pathogenic for the domestic fowl. Am. Jour. Hyg. 27:615-18.
- GINGRICH, W. D.
1948. Duration of immunity to malaria (*Plasmodium cathemerium*) in the canary. Jour. Natl. Mal. Soc. 7:109-17.

- HEWITT, R.
1942. Studies on the host-parasite relationships of untreated infections with *Plasmodium lophurae* in ducks. *Am. Jour. Hyg.* 36: 6-40.
- , A. P. RICHARDSON, AND L. D. SEAGER
1942. Observations on untreated infections with *Plasmodium lophurae* in twelve hundred young White Pekin ducks. *Ibid.* 36: 362-73.
- HUFF, C. G., F. COULSTON, R. L. LAIRD, AND R. J. PORTER
1947. Pre-erythrocytic development of *Plasmodium lophurae* in various hosts. *Jour. Inf. Dis.* 81: 7-13.
- HURLBURT, H. S., AND R. HEWITT
1942. The transmission of *Plasmodium lophurae*, an avian malaria parasite, by *Anopheles quadrimaculatus*. *Pub. Hlth. Rep.* 57: 1891-92.
- JEFFERY, G. M.
1944. Investigation of the mosquito transmission of *Plasmodium lophurae* Coggeshall, 1938. *Am. Jour. Hyg.* 40: 251-63.
- LAIRD, R. L.
1941. Observations on mosquito transmission of *Plasmodium lophurae*. *Am. Jour. Hyg.* 34(C): 163-67.
- MANWELL, R. D.
1943. Malaria infections by four species of *Plasmodium* in the duck and chicken, and resulting parasite modifications. *Am. Jour. Hyg.* 38: 211-23.
- MARSHALL, E. K., J. T. LITCHFIELD, AND H. J. WHITE
1942. Sulfonamide therapy of malaria in ducks. *Jour. Pharm. and Exper. Therap.* 75: 89-104.
- TALIAFERRO, W. H., AND L. G. TALIAFERRO
1940. Active and passive immunity in chickens against *Plasmodium lophurae*. *Jour. Inf. Dis.* 66: 153-65.
- , AND ———
1945. Immunological relationships of *Plasmodium gallinaceum* and *Plasmodium lophurae*. *Ibid.* 77: 224-48.
- TERZIAN, L. A.
1941. Studies on *Plasmodium lophurae*, a malarial parasite in fowls. I. Biological characteristics. *Am. Jour. Hyg.* 33: 1-22.
- 1941a. *Ibid.* II. Pathology and effects of experimental conditions. *Ibid.* 33: 33-53.
- WOLFSON, F.
1940. Virulence and exo-erythrocytic schizogony in four species of *Plasmodium* in domestic ducks. *Jour. Parasit.* 26 (Suppl.): 28.
- 1941. Avian hosts for malaria research. *Quar. Rev. Biol.* 16: 462-73.

REPORT ON EUROPEAN CORN BORER RESISTANCE INVESTIGATIONS¹

S. D. BECK AND J. H. LILLY²

Departments of Zoology and Economic Entomology, University of Wisconsin

Received April 6, 1949

INTRODUCTION³

The work reported herein was carried out in an effort to determine the factor or factors responsible for the differences in susceptibility to attack by larvae of the European corn borer, *Pyrausta nubilalis* Hubn. that reportedly are displayed by different varieties of corn. The European corn borer is a major pest in the corn belt of the United States. None of the control measures now practiced by commercial corn producers adequately solves the problem of preventing or curbing the ravages of this insect.

One approach to the problem of combating the corn borer has been through attempts to develop varieties of corn that display a comparatively high resistance to its attack. Although corn breeding programs have made substantial progress, no immune or near-immune varieties have been produced to date. The present work was initiated because it was believed that a knowledge of the factors involved in resistance of the plant would be of great benefit to these breeding programs. The experimental work conducted on this problem has been of an exploratory nature, several possibilities being considered and explored in the hope of obtaining a lead that would justify further and more exhaustive investigation. Some phases of the investigation have shown promise and are to be expanded in future work.

As pointed out by Everly (6), the resistance problem in respect to the corn borer resolves itself into three phases: (1) the oviposition preferences of the female moths, (2) the survival of the larvae, and (3) the tolerance and ability to recover of the corn plant. In this work we have been concerned only with the survival and growth of the larvae.

MATERIALS AND METHODS

The work described in this report involved the laboratory rearing of newly-hatched corn borer larvae on green plant material. The larvae,

¹This investigation was supported in part by the Research Committee of the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation. Approved for publication by the Director of the Wisconsin Agricultural Experiment Station.

²Now professor of Entomology, Iowa State College.

³The authors gratefully acknowledge the cooperation of Professor J. F. Stauffer during the progress of this work.

from field-collected eggs incubated and hatched in the laboratory, were used within a few hours after hatching, and without having had an opportunity to feed. They were reared in shell vials of about 25 milliliters capacity, four larvae being placed on the plant tissue held by such a vial.

The plant material used was grown in the Horticultural Gardens on the campus of the University of Wisconsin. Plots containing two corn hybrids and two varieties of sweet sorghum were planted at frequent intervals, making it possible to obtain plants of different sizes and varieties at any time. One "susceptible" dent corn hybrid (WF9 x 187) and one "resistant" hybrid (R4 x Hy) were used. The sorghum varieties planted were amber cane and South Dakota selection "20-30-S." The latter strain was supposedly high in cyanide content and the former much lower.

For use in the feeding experiments, plants were selected according to their vertical height and the length of the longest leaf from ground to tip. In the data presented, however, only the height is indicated. The leaves of the plants selected were cut into sections about two inches in length, and several sections were placed together and rolled into a cylindrical bundle. The ends of this bundle were then dipped into molten paraffin to seal the cut ends and thus conserve moisture and help preserve the form of the rolled bundle.

The plant material, prepared as described above, was placed in a sterile shell vial, the larvae were added, the vial plugged with cotton, and the whole placed in an incubator maintained at a temperature of about 80°F. At the end of seventy-two hours the surviving larvae were transferred to vials containing fresh plant material. They were again placed in the incubator, and at the end of a second seventy-two-hour period the culture was examined, the larvae weighed, and the experiment terminated.

EXPERIMENTAL RESULTS

1. PLANT SIZE AND SUSCEPTIBILITY

It is a common field observation that young corn plants under about sixteen inches in height are seldom attacked by corn borer larvae. Neiswander (8) reports that when only corn plants less than sixteen inches in height are available, the moths prefer to lay their eggs on other plants, such as potatoes or oats. The failure of the moths to oviposit on small plants is thought to be correlated with the unsuitability of such plants as food material for the newly-hatched larvae.

In testing this hypothesis, a series of experiments was carried out in which leaves from various-sized plants of two corn hybrids, one "resistant" and one "susceptible," were used as food material for newly-hatched larvae.

Results

The mortality encountered among the larvae reared on the leaves of plants of various sizes (Fig. 1) shows that the "resistant" hybrid

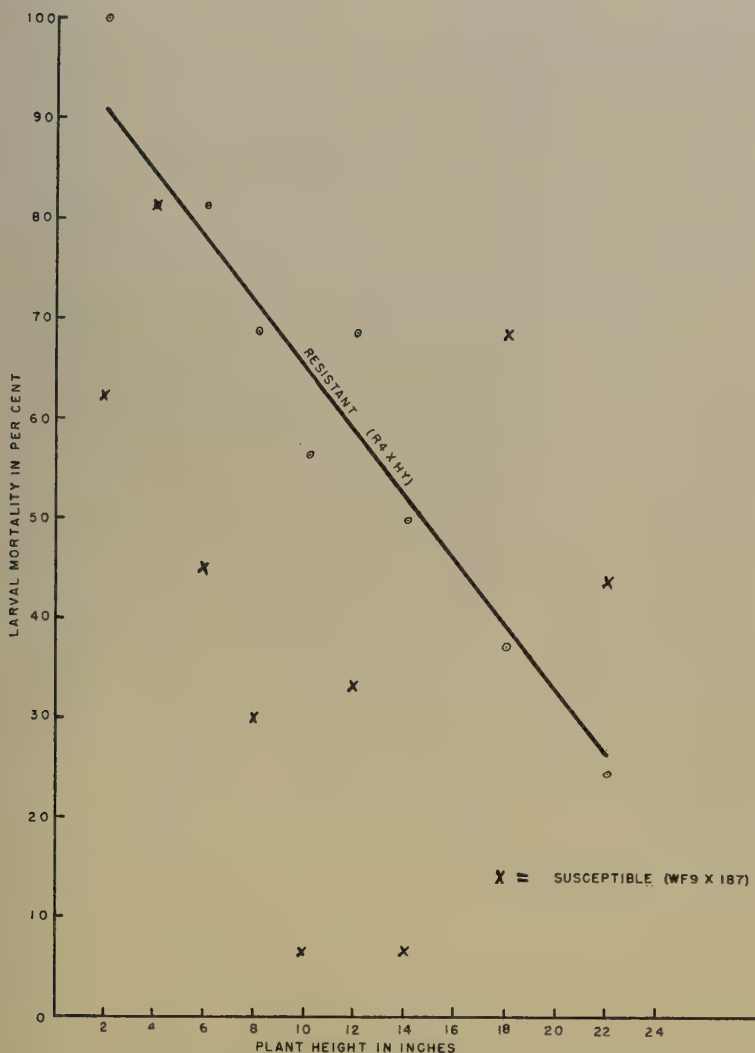


FIG. 1.—Plant size and mortality of newly hatched corn borer larvae on "resistant" and "susceptible" dent corn hybrids.

plant became progressively more suitable to the borer larvae as it increased in height. In the case of the more susceptible hybrid the improvement as a food plant was not so apparent and was much less consistent. However, a tendency appeared for the mortality to decrease as the plant height increased.

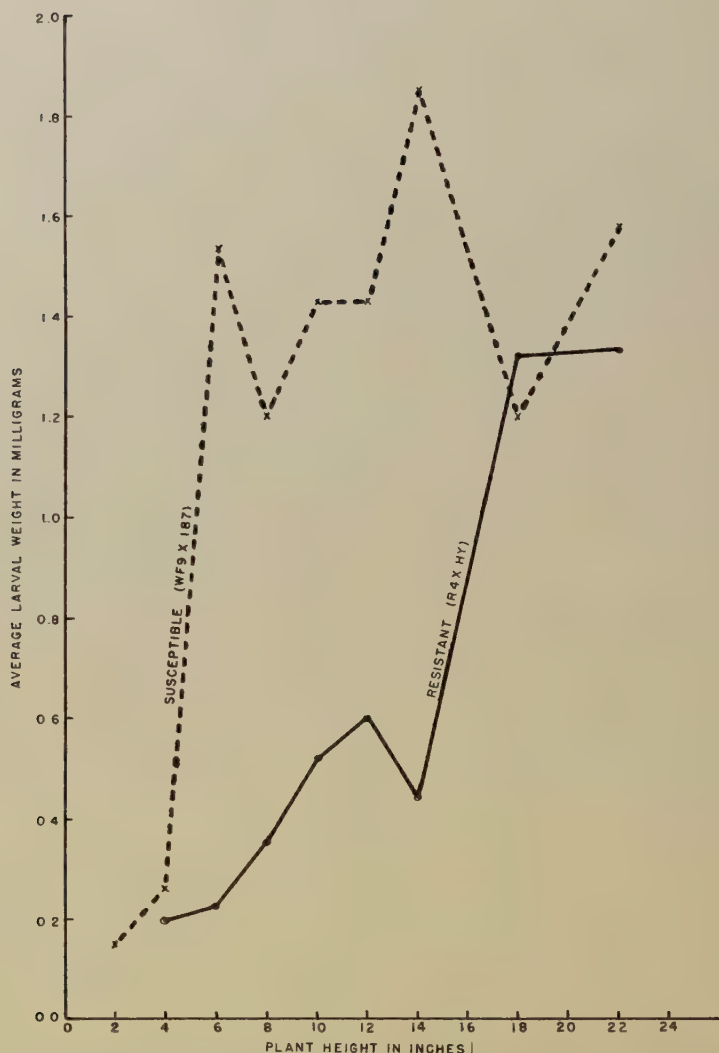


FIG. 2.—Weights of young corn borer larvae after feeding 144 hours on leaves of "resistant" and "susceptible" dent corn hybrids.

The larvae surviving at the termination of the 144-hour period were weighed. The average weights attained in each series are presented in Figure 2. These data show the same trend as the data on larval mortality, i.e., the plants of both hybrids became more suitable for larval development as they increased in height.

Conclusion

The results of these experiments show that a difference existed between the two hybrids when the plants were young, the "resistant" hybrid being much less suitable for the young borers than the more susceptible one. It is of interest to note, however, that this difference tended to disappear as the plants reached a height of about eighteen inches; this tendency is apparent from both the data on mortality and those on larval weights. It is also apparent that the leaves of the more susceptible hybrid became adequate for good larval growth at a much earlier stage (height) than was the case with the leaves of the resistant hybrid (Fig. 2). The data presented are too limited in extent to permit drawing definite conclusions, but the working hypothesis might be advanced that the unsuitability of the so-called resistant hybrids and varieties is most pronounced and effective during the early stages of growth of the plants. It would appear that the factor or factors responsible for the resistance disappear or become less effective as the plants grow.

2. PLANT ACIDITY AND SUSCEPTIBILITY

In an effort to explain differences in susceptibility of different varieties and strains of corn to attacks by borer larvae, Baugh (1) measured the total acidity of the various plant parts of several varieties and reported a correlation between titratable acidity and borer infestation. He presented data showing that a high acid content of the plant was accompanied by a low infestation. Sayre (9) was not able to confirm these results. Work conducted in this laboratory in previous years also has failed to confirm Baugh's findings.

In view of the fact that all of the above work was carried out on mature or nearly mature plants, this series of experiments was designed to determine whether or not differences in susceptibility might be explained on the basis of differences in total acidity displayed by plants less than two feet in height. These experiments were run at the same time and with the same plant material as in the plant size study described in the previous section.

Method

For the acid determinations, the sap was expressed from the plant tissues not used for feeding by means of a hydraulic press. Ten milliliters of this expressed juice were titrated with dilute (.041 N) sodium hydroxide from the original pH to a pH of about 9. The pH determinations and titrations were carried out with a Beckman electric pH meter. For the purposes of comparing the titratable acidity of the different samples the amount of base required to raise the pH from 6.0 to 8.0 was read from a graph of the titration curve obtained in each case.

Results

Comparisons of the pH of juice expressed from the various leaf samples of the two hybrids tested (Table 1) show no differences in pH

that might explain the differences in larval survival. The titratable acidity of the leaves of the two hybrids (Fig. 3) declined as the plants increased in size.

Conclusion

It has been shown in the preceding section that larval mortality decreased as the plants increased in size. This decrease in mortality was accompanied by a decrease in total acidity (Table 1 and Fig. 3). If the decrease in mortality was due to the decrease in acidity, it seems logical

TABLE 1
pH OF SAP EXPRESSED FROM LEAVES OF "RESISTANT" AND "SUSCEPTIBLE"
DENT CORN HYBRIDS

Plant Height (inches)	pH	
	Resistant (R4 × Hy)	Susceptible (WF9 × 187)
2.....	5.42	5.58
4.....	5.75	5.00
6.....	5.26	5.44
8.....	5.33	5.65
10.....	6.01	5.70
12.....	6.08	5.39
14.....	5.48	5.90
18.....	5.92	5.55
22.....	5.95	5.99

that the differences between larval mortality on leaves of a "resistant" hybrid and that of those on leaves of a "susceptible" hybrid would be accompanied by corresponding differences in plant acidity. The leaf data (Fig. 3) show no consistent differences between the acidity of the two hybrids. The differences in mortality and development encountered, as shown in the preceding section, show no correlation with either the pH or the titratable acidity of expressed plant saps, as they were measured in these experiments.

3. CYANOGENESIS AND SUSCEPTIBILITY

Sorghum, although closely related to corn, shows a marked resistance to attack by the European corn borer. Since sorghum is known to be cyanogenetic to a much greater degree than corn, a series of experiments was run to determine whether or not the difference in susceptibility to the corn borer could be explained on this basis. The HCN content of the leaves was determined by the colorimetric method used by Boyd *et al.* (3). The determinations were made on a photoelectric colorimeter, and are expressed as parts per million (p.p.m.) of oven dried leaves. Young corn borer larvae were reared on the parts of the leaf samples not utilized for the cyanide determinations.

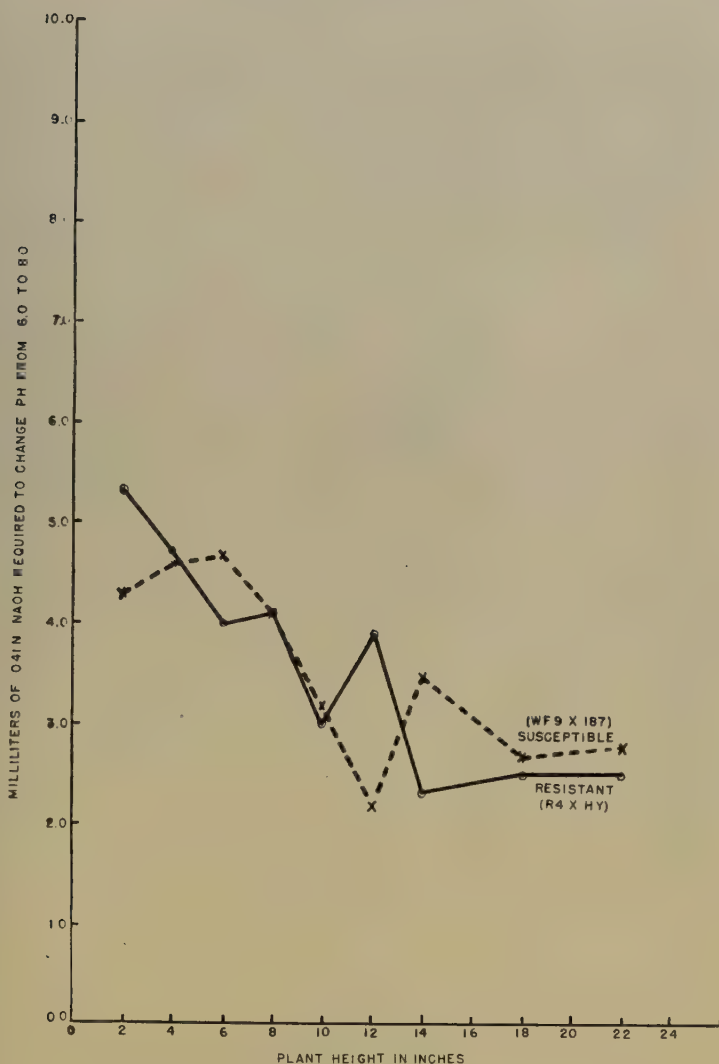


FIG. 3.—Total acidity of expressed leaf sap of two dent corn hybrids.

Results and Conclusions

The results of the cyanide experiments on sorghum (Fig. 4) indicate that the cyanogenetic properties of sweet sorghum are responsible, at least in part, for the high insect resistance displayed by this plant as compared to corn. In view of the correlation between larval mortality

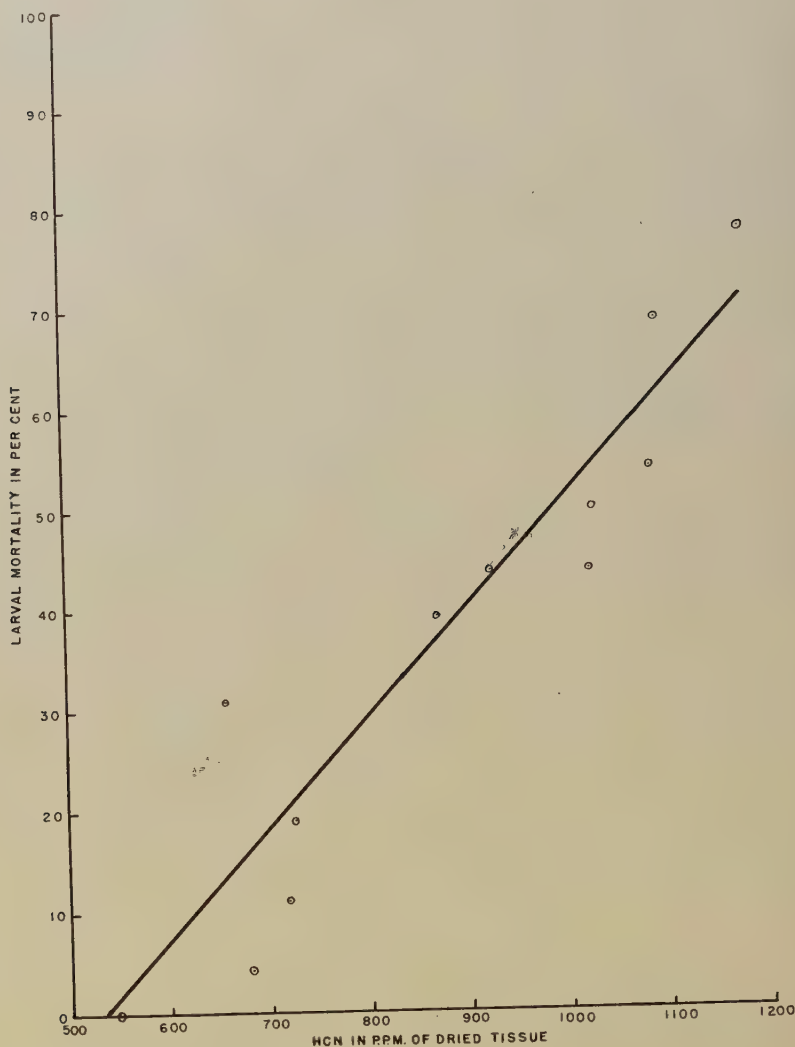


FIG. 4.—Mortality of young corn borer larvae reared on sorghum leaves of varying HCN contents.

and cyanide content found in sweet sorghum, a series of experiments was conducted in which corn leaves were used for feeding the larvae and for cyanide determinations by the same method. The data obtained from the experiments on corn (Table 2) disclose no correlation between larval mortality and the cyanide level found in the leaves.

TABLE 2
MORTALITY OF FIRST AND SECOND INSTAR CORN BORER LARVAE ON LEAVES OF
FIELD CORN OF DIFFERENT CYANIDE CONTENTS

No. of Larvae Used	HCN	Mortality in 72 Hrs.
	(<i>p.p.m.</i>)	(<i>percentage</i>)
16.....	19	37.5
6.....	16	87.5
33.....	13	63.6
49.....	12	55.1
9.....	11	71.5
10.....	10	70.0
20.....	9	20.0
16.....	8	68.7
16.....	4	68.7

In the light of the data on sorghum, which show that a level of 500 p.p.m. or higher can be tolerated by some of the larvae, it is hardly to be expected that the extremely low cyanide levels encountered in corn can be interpreted as being an important resistance factor.

4. CARBOHYDRATE DEFICIENCY AND SUSCEPTIBILITY

The possibility that the high mortality, encountered when newly-hatched larvae were fed on leaves of corn plants with a vertical height of six inches or less, might be the result of a low carbohydrate content of these plants was considered worth investigating. The sugar supply has been shown to be the limiting factor for a number of insects. Comes (4) attributed the decline of resistance of several plants to increasing sugar and decreasing organic acid levels during the course of their development. Emery (5) found that alfalfa plants resistant to attacks of the pea aphid were low in sugars. Metzger *et al.* (7) reported that sugar content is an important factor in determining whether or not a particular plant will be susceptible or resistant to the attack of the Japanese beetle. Bottger (2) found in the case of the European corn borer, the larvae reacted much more favorably to a food plant high in sugar than to one low in such substances. It seemed logical,

TABLE 3
LARVAL SURVIVAL AND GROWTH ON FOUR-INCH CORN PLANTS SUPPLEMENTED WITH
GLUCOSE SOLUTIONS

No. Larvae Used	Glucose Solution Used	Mortality		Av. Weight at 144 Hrs.
		72 Hrs.	144 Hrs.	
	(<i>percentage</i>)	(<i>percentage</i>)	(<i>percentage</i>)	(<i>mgm</i>)
16.....	0.0	81.2	100.0	.....
16.....	1.0	75.0	100.0	.....
16.....	5.0	62.5	87.5	0.1
16.....	10.0	56.2	75.0	0.5
16.....	25.0	25.0	62.5	0.7

TABLE 4
LARVAL SURVIVAL AND GROWTH ON SIX-INCH CORN PLANTS SUPPLEMENTED WITH
GLUCOSE SOLUTIONS

No. Larvae Used	Glucose Solution Used	Mortality		Av. Weight at 144 Hrs.
		72 Hrs.	144 Hrs.	
	(percentage)	(percentage)	(percentage)	(mgm)
16.....	0.0	68.7	93.7	0.4
16.....	5.0	87.5	93.7	0.2
16.....	10.0	87.5	87.5	0.4
16.....	20.0	50.0	56.2	0.8

therefore, to see whether or not the mortality on very small plants could be reduced by supplementing the plants with sugars.

Small plants of the two hybrids were brought into the laboratory where the stems were cut and the cut ends immersed in a sugar solution for about twenty-four hours. The leaves of the treated plants were then used for feeding newly-hatched larvae.

Results

The results of this work (Tables 3, 4, and 5) show that supplementing the plants with either glucose or sucrose resulted in a marked increase in both larval survival and larval growth, as reflected by the weights of the surviving larvae at the end of the experimental period.

Conclusion

Although final conclusions are not being drawn from these experiments, the results are interpreted as indicating that young corn borer larvae have a higher sugar requirement than is met by corn plants up to six inches in height.

SUMMARY

1. When fed on leaves of the "resistant" dent corn hybrid (R4 x Hy), the mortality of newly-hatched European corn borer larvae was higher and the development was slower than in the case of larvae fed

TABLE 5
LARVAL SURVIVAL AND GROWTH ON SIX-INCH CORN PLANTS SUPPLEMENTED WITH
SUCROSE SOLUTIONS

No. Larvae Used	Sucrose Solution Used	Mortality		Av. Weight at 144 Hrs.
		72 Hrs.	144 Hrs.	
	(percentage)	(percentage)	(percentage)	(mgm)
16.....	0.0	68.7	87.5	0.6
16.....	5.0	75.0	93.7	0.2
16.....	10.0	50.0	62.5	0.6
16.....	20.0	50.0	62.5	1.3

on leaves of the "susceptible" hybrid (WF9 x 187). The differences in larval survival and development were great on young plants, but became less evident as the plants developed.

2. The observed differences in larval mortality and growth on the two hybrids apparently cannot be explained on the basis of differences in the acidity of the plants, measured either as pH or as total (titratable) acidity. However, the total acidity of the young corn plants tested tended to decrease as they grew larger.

3. The cyanogenetic property of sweet sorghum appears to be an important factor in the resistance of that plant to attacks by young corn borer larvae, since a direct correlation was found between larval mortality and the amount of HCN generated by the sorghum host plants. The corn hybrids were cyanogenetic to a much smaller degree, and no such correlation was detected in them.

4. The sugar content of very young corn plants appears to be inadequate to meet the nutritional requirements of newly-hatched borer larvae. Both the survival and growth of young larvae fed on them were greatly improved by supplementing the plants with either glucose or sucrose.

LITERATURE CITED

1. BAUGH, R. H.
1928. The relationship between the stage of maturity of varieties of corn plants and the amount of European corn borer moth eggs with sugar and acid analyses of varieties of varying infestation. M. S. Thesis, Michigan State College of Agriculture and Applied Science.
2. BOTTGER, G. T.
1940. Preliminary studies of the nutritive requirements of the European corn borer. *Jour. Agr. Res.* 60:249-57.
3. BOYD, F. T., O. S. AAMODT, G. BOHSTEDT, AND E. TRUOG
1938. Sudan grass management for control of cyanide poisoning. *Jour. Amer. Soc. Agron.* 30(7):569-82.
4. COMES, H.
1916. La prophylaxen patologia vegetal. *Bol. de Agr. Tecnica y Economica Madrid* 9(102):508-14. *Abst. Rev. Appl. Ent. A* 6:55-66. 1918.
5. EMERY, W. T.
1946. Temporary immunity in alfalfa ordinarily susceptible to attack by the pea aphid. *Jour. Agr. Res.* 73(2):33-43.
6. EVERLY, R. T.
1946. Resistance studies with the European corn borer. *Proc. 25th Ann. Meet. North Central States Branch of Amer. Assoc. Econ. Entomologists.* Pp. 82-83.
7. METZGER, F. W., P. A. VANDER MUELEN, AND C. W. MELL
1934. The relation of the sugar content and odor of clarified extracts of plants to their susceptibility to attack by the Japanese beetle. *Jour. Agr. Res.* 49(11):1001-08.
8. NEISWANDER, C. R.
1945. The European corn borer in market garden sweet corn. *Proc. Ann. Meet. Ohio Veg. and Potato Growers' Assoc.* 30:35-45.
9. SAYRE, J. D.
1930. H-ion concentration and buffer action of expressed sap from corn. *Ohio Agr. Exp. Sta. 48th Annual Rpt. Bull.* 446 pp. 38-39.

SECOND SUPPLEMENTARY LIST OF PARASITIC FUNGI FROM IOWA¹

JOSEPH C. GILMAN

*From the Botany and Plant Pathology Section
Iowa Agricultural Experiment Station, Ames, Iowa*

Received April 22, 1949

The population of parasitic fungi in any area is not static but changes continually: by the introduction of new hosts and also of new fungi as the agriculture of the area changes. Hence, lists supplemental to those already published (22, 23) are needed to record these changes. The present list (third in this series) brings together forty-four new fungi for the state, and eighteen fungi on hosts hitherto unreported in these lists. Of new hosts, forty-seven occur.

Examination of the species of parasites and hosts, if they are compared with the previous lists, suggests two significant facts in the study of such populations. The predominance of grass hosts, 51 of 107 possibilities, was primarily effected by the growing of a grass garden in connection with the Botany Department at Ames. Concentrating a large number of species of plants from one family into a small area favored the outbreak of an epiphytotic of *Claviceps purpurea*. The other fact was the reporting of seven fungi on soybean, an instance of the introduction of a new crop gradually becoming attacked by an increasing number of parasites as the time of exposure and the population both increased.

This list brings the total number of parasitic fungi reported for the state to 1013 and the number of hosts to 1082. As in previous lists the figure in parentheses after the fungus name refers to a citation in which the fungus is described, after the host name to a record of the occurrence of the fungus on that host in Iowa. The species of fungi not hitherto listed are indicated by the asterisk preceding them in the list.

The assistance of Dr. G. W. Martin of the State University, Mrs. Lois H. Tiffany and Miss Frances Meehan, as well as various other members of the Department of Botany is gratefully acknowledged.

¹ Journal Paper No. J1639 of the Iowa Agricultural Experiment Station, Ames, Iowa, Project No. 450.

INDEX TO FUNGI

1. * **Aphanomyces cochlioides** Drechsl. (15)
On *Beta vulgaris* L. (11)
2. * **Botryosphaeria ribis** G. and D. (26)
On *Rhus glabra* L. (9)
On *Rhus typhina* Torn. (9)
3. * **Calonectria rubescens** (Robs.) Sacc. (42)
On samaras of *Ulmus* sp.
On capsules of *Populus* sp.
Story Co.: Brooks, 1942.
4. * **Cephalosporium gregatum** Allington & Chamberlain (2)
On *Glycine max* Merr. (2)
5. **Cercospora clavata** (Gerard) Pk. (16)
On *Asclepias speciosa* Torr.
Dewey H 8, Ruthven: Hayden, 1944.
6. * **Cercospora cruciferarum** Ell. & Ev. (17)
On *Sisymbrium officinale* (L.) Scop.
Soper's Mill: Gilman, 1941.
7. * **Cercospora muhlenbergiae** Atk. (6)
On *Muhlenbergia mexicana* (L.) Trin.
Belmond: Koepper, 1941.
8. * **Cercospora seminalis** Ell. & Ev. (18)
On *Buchloe dactyloides* (Nutt.) Engelm.
Herbaceous garden, Ames: Meehan, 1944.
9. * **Chalara quercina** Henry (28)
On *Quercus alba* L. (14)
On *Quercus borealis* Michx. (14)
On *Quercus ellipsoidalis* E. J. Hill (14)
On *Quercus imbricaria* Michx. (14)
On *Quercus macrocarpa* Michx. (14)
On *Quercus marilandica* Muench. (14)
On *Quercus muhlenbergii* Engelm. (14)
On *Quercus palustris* Muench. (14)
On *Quercus velutina* Lam. (14)
10. * **Choanephora cucurbitarum** (B. & R.) Thax. (51)
On *Cucurbita moschata* Duchesne (Summer squash)
Ames: Gilman, 1943.
11. **Claviceps purpurea** (Fr.) Tul. (5)
On *Agropyron cristatum* (Schreb.) Gaertn. (44)
Herbaceous garden, Ames: Gilman, 1943.
On *Agropyron inerme* (Scribn. & Smith) Rydb. (44)

- On *Agropyron pauciflorum* (Schw.) Hitchc. (44)
 On *Agropyron trichophorum* (Link) Richt. (44)
 On *Agrostis canina* L. (44)
 On *Alopecurus pratensis* L. (44)
 On *Arrhenatherum elatius* (L.) Beauv. (44)
 On *Arrhenatherum tuberosum* Schultz (44)
 On *Bromus commutatus* Schrad. (44)
 On *Bromus japonicus* Thunb. (44)
 On *Bromus marginatus* Nees (44)
 On *Bromus polyanthus* Scribn. (44)
 On *Bromus purgans* L. (44)
 On *Bromus secalinus* L. (44)
 On *Calamagrostis canadensis* (Michx.) Beauv.² (44)
 On *Calamagrostis epigeios* (L.) Roth (44)
 On *Dactylis glomerata* L. (44)
 Herbaceous garden, Ames: Gilman, 1943.
 On *Deschampsia caespitosa* (L.) Beauv. (44)
 On *Elymus condensatus* Presl. (44)
 On *Elymus condensatus* x *Mosida* wheat (44)
 On *Elymus glaucus* Buckley (44)
 On *Elymus giganteus* Vahl. (44)
 On *Festuca arundinacea* Schreb. (44)
 On *Festuca elatior* L. (44)
 On *Festuca ovina* L. (44)
 On *Festuca rubra* L. (44)
 On *Lolium perenne* L. (44)
 On *Phalaris arundinacea* L. (44)
 On *Phalaris californica* Hook. & Arn. (44)
 On *Phalaris canariensis* L. (44)
 On *Phalaris caroliniana* Walt. (44)
 On *Poa arachnifera* Torr. x *Poa pratensis* L. (44)
 On *Poa compressa* L. (44)
 On *Stipa viridula* Trin. (44)
12. * *Claviceps pusilla* Ces. (5)
 On *Andropogon furcatus* Muhl. (44)
 On *Andropogon hallii* Hack. (44)
 On *Andropogon scoparius* Michx. (44)
13. * *Coleosporium ipomoeae* Burr. (4)
 On *Ipomoea hederacea* Jacq.
 Oskaloosa: Sylwester, 1944.
 On *Ipomoea pandurata* (L.) G. W. Mey. (7)

² *Claviceps microcephala* (Wallr.) Tul. was reported on *Calamagrostis canadensis* by Gilman and Archer (23). Conidial measurements made by Tiffany (44) at the time of publication of her paper indicated that the ergot on this host is more likely to be *Claviceps purpurea*.

14. * *Colletotrichum fusarioides* (Ell. & Kellerm.) O'Gara (37)
On *Asclepias speciosa* Torr.
Dewey's pasture, Ruthven: Hayden, 1944.
15. * *Colletotrichum linicola* Peth. & Laf. (39)
On *Linum usitatissimum* L.
Kanawha: Reddy, 1943.
16. *Cronartium ribicola* Fisch. de Waldh. (4)
On *Ribes hudsonianum* Richards
Bixby Park: E. Wilson, 1942.
17. *Darluca filum* (Biv.) Cast. (41)
On *Puccinia graminis* Pers. on *Dactylis glomerata* L.
Ames: Taylor, 1947.
18. * *Diaporthe phaseolarum* var. *batatatis* (46)
On *Glycine max* Merr. (49)
Ames: Welch, 1947.
19. * *Diaporthe phaseolarum* var. *sojae* Lehm. (46)
On *Glycine max* Merr. (49)
Ames: Welch, 1947.
20. * *Diderma effusum* var. *reticulatum* (Rost.) Macbride (33)
On *Fragaria* sp. (cult. strawberry)
Cedar Rapids: Kent, 1943.
21. * *Diplodia asclepiadea* C. & E. (40)
On *Asclepias verticillata* L.
Ledges State Park: Brooks, 1942.
22. *Frommea obtusa* (Str.) Arth. (*Phragmidium obtusum*) (4)
On *Potentilla simplex* Michx. (*P. canadensis* auth.)
Lansing: Dolan and Barthell, 1945.
23. * *Gloeosporium betularum* E. & M. (20)
On *Betula nigra* L.
MacGregor: Kent, 1934.
24. * *Gloeosporium sphaerella* Sacc. (40)
On *Hoya carnosa* R. Br. (wax plant)
Eldora: Waldee, 1943.
25. *Gloeosporium trifolii* Pk. (38)
On *Melilotus* sp.
Ames: Davy, 1942.
26. * *Glomerella glycines* Lehm. and Wolf (30)
On *Glycine max* Merr.
Ames: Tiffany, 1948.

27. * *Helminthosporium victoriae* Meehan & Murphy (35)
On *Avena sativa* L. (35)
28. * *Herpobasidium deformans* Gould (24) (*Glomerularia corni* Pk.)
On *Lonicera tatarica* L.
Ames: Gould, 1941.
29. * *Leptosphaeria avenaria* Weber (45)
On *Avena sativa* L. (36)
30. * *Linospora gleditsiae* (Lev.) Miller and Wolf (32)
On *Gleditsia tricanthos* L.
Iowa City: G. W. Martin, 1942.
31. *Marssonina brunnea* (Ell. & Ev.) Sacc. (19)
On *Populus tremuloides* Michx.
Shelby: Gilman and Cohen, 1948.
32. *Melampsora abietis-canadensis* (Farl.) Ludw. (4)
On *Populus grandidentata* Michx.
North Liberty: G. W. Martin, 1941.
33. * *Mycosphaerella citrullina* (Sm.) Gros. (25)
On *Cucumis melo* L.
Des Moines: Knuths, 1939.
34. * *Nectria ipomoeae* Halst. (42)
On *Ipomoea batatis* Poir
Conesville: Hooker, 1948.
35. * *Ophiobolus fulgidus* (C. & P.) Sacc. (40)
On *Ambrosia trifida* L.
Crystal Lake: Wadley, 1942.
36. * *Peronospora manshurica* (Naum.) Syd. (21)
On *Glycine max* Merr. (48)
37. * *Phomopsis strobis* Syd. (40)
On *Pinus strobus* L.
Ames: Young, 1942.
38. *Phragmidium speciosum* Cke. (4)
On *Rosa rugosa* Thunb.
Ruthven: Hayden, 1943.
39. * *Pseudomonas tabaci* (Wolf and Foster) Stev. (8)
On *Glycine max* Merr. (1)
40. * *Pseudoperonospora humuli* Miyabe and Takah. (4)
On *Humulus lupulus* L.
Ames: Sylwester, 1944.

41. **Puccinia angustata** Arth. (4)
On *Pycnanthemum pilosum* Nutt. (7)
42. **Puccinia coronata** Cda. (4)
On *Lolium multiflorum* Lam.
Marshalltown: Vestal, 1944.
43. **Puccinia extensicola oenotherae** (Mont.) Arth. (4) (*Puccinia peckii* Kellerm.)
On *Carex lacustris* Willd.
Ruthven: Hayden, 1944.
44. **Puccinia graminis** Pers. (4)
On *Panicum dichotomiflorum* Michx.
Iowa City: G. W. Martin, 1930.
45. * **Puccinia physostegiae** P. and C. (4)
On *Physostegia virginiana* (L.) Benth. (7)
46. **Puccinia vernoniae** Schw. (4)
On *Vernonia illinoensis* Gleason (7)
47. * **Puccinia windsoriae** Schw. (4)
On *Triodia flava* (L.) Hitchc. (7)
48. * **Pythium debaryanum** Hesse (34)
On *Avena sativa* L. (47)
On *Beta vulgaris* L. (10)
49. * **Pythium graminicola** Subr. (34)
On *Hordeum vulgare* L. (29)
On *Setaria glauca* (L.) Beauv. (29)
50. * **Pythium irregulare** Buisman (34)
On *Citrullus vulgaris* Schrad. (53)
51. **Sclerotinia sclerotiorum** (Lib.) Schroet. (*S. libertiana* Fckl.) (52)
On *Glycine max* Merr. (48)
52. * **Sclerotium rolfsii** Sacc. (43)
On *Trifolium pratense* L.
Ames: Tiffany, 1948.
53. * **Septoria acicola** (Thuem.) Sacc. (40)
On *Pinus ponderosa* Douglas (Cult.)
Rockwell City: Harding, 1947.
54. * **Septoria bacilligera** Wint. (50)
On *Ambrosia trifida* L.
Crystal Lake: Wadley, 1942.
55. * **Sorosporium everhartii** Ell. and Gall. (15)
On *Andropogon furcatus* Muhl.
Ames: Meehan, 1944.

56. * *Sphacelotheca ischaemi* (Fekl.) Clint. (12)
On *Andropogon scoparius* Michx.
Conesville: Coe, 1944.
57. * *Sphaeropsis pinastri* (Lev.) Sacc. (40)
On *Picea abies* (L.) Karst.
Ames: Gilman, 1945.
58. * *Stagonospora zonata* J. J. Davis (13)
On *Asclepias ovalifolia* Dene.
Clay Co.: Hayden, 1944.
59. *Urocystis agropyri* (Preuss) Schroet. (12)
On *Poa pratensis* L.
Ames: Meehan, 1945.
60. *Uromyces hedysari-paniculatae* (Schw.) Farl. (4)
On *Desmodium paniculatum* (L.) D. C. (7)
61. *Ustilago hypodytes* (Schlect.) Fr. (12)
On *Stipa viridula* Trin.
Ames: Sons, 1941.
62. *Xenosporella larvalis* (Morgan) Linder. (31)
On *Tecoma radicans* (L.) Juss.
Waterloo: Waldee, 1943.

HOST INDEX

- | | |
|--|--|
| <p><i>Agropyron cristatum</i> (Schreb.) Gaertn.
 <i>Claviceps purpurea</i></p> <p><i>Agropyron inerme</i> (Scribn. & Sm.)
 Rydb.
 <i>Claviceps purpurea</i></p> <p><i>Agropyron pauciflorum</i> (Schw.) Hitchc.
 <i>Claviceps purpurea</i></p> <p><i>Agropyron trichophorum</i> (Link) Richt.
 <i>Claviceps purpurea</i></p> <p><i>Agrostis canina</i> L.
 <i>Claviceps purpurea</i></p> <p><i>Alopecurus pratensis</i> L.
 <i>Claviceps purpurea</i></p> <p><i>Ambrosia trifida</i> L.
 <i>Ophiobolus fulgidus</i>
 <i>Septoria bacilligera</i></p> <p><i>Andropogon furcatus</i> Muhl.
 <i>Claviceps pusilla</i>
 <i>Sorosporium everhartii</i></p> <p><i>Andropogon hallii</i> Hack.
 <i>Claviceps pusilla</i></p> <p><i>Andropogon scoparius</i> Michx.
 <i>Claviceps pusilla</i>
 <i>Sphacelotheca ischaemi</i></p> | <p><i>Arrhenatherum elatius</i> (L.) Beauv.
 <i>Claviceps purpurea</i></p> <p><i>Arrhenatherum tuberosum</i> Schultz
 <i>Claviceps purpurea</i></p> <p><i>Asclepias ovalifolia</i> Dene.
 <i>Stagonospora zonata</i></p> <p><i>Asclepias speciosa</i> Torr.
 <i>Cercospora clavata</i>
 <i>Colletotrichum fusarioides</i></p> <p><i>Asclepias verticillata</i> L.
 <i>Diplodia asclepiadis</i></p> <p><i>Avena sativa</i> L.
 <i>Helminthosporium victoriae</i>
 <i>Leptosphaeria avenaria</i>
 <i>Pythium debaryanum</i></p> <p><i>Beta vulgaris</i> L.
 <i>Aphanomyces cochlioides</i>
 <i>Pythium debaryanum</i></p> <p><i>Betula nigra</i> L.
 <i>Gloeosporium betularum</i></p> <p><i>Bromus commutatus</i> Schrad.
 <i>Claviceps purpurea</i></p> |
|--|--|

- Bromus japonicus** Thunb.
Claviceps purpurea
- Bromus marginatus** Nees
Claviceps purpurea
- Bromus polyanthus** Scribn.
Claviceps purpurea
- Bromus purgans** L.
Claviceps purpurea
- Bromus secalinus** L.
Claviceps purpurea
- Buchloe dactyloides** (Nutt.) Engelm.
Cercospora seminalis
- Calamagrostis canadensis** (Michx.) Beauv.
Claviceps purpurea
- Calamagrostis epigeios** (L.) Roth.
Claviceps purpurea
- Carex lacustris** Willd.
Puccinia extensicola var. *oenotherae*
- Citrullus vulgaris** Schrad.
Pythium irregulare
- Cucumis melo** L.
Mycosphaerella citrullina
Pythium irregulare
- Cucurbita moschata** Dcne.
Choanephora cucurbitarum
- Dactylis glomerata** L.
Claviceps purpurea
- Deschampsia caespitosa** (L.) Beauv.
Claviceps purpurea
- Desmodium paniculatum** (L.) D.C.
Uromyces hedysari-paniculatae
- Elymus condensatus** Presl.
Claviceps purpurea
- Elymus condensatus** x *Mosida* wheat
Claviceps purpurea
- Elymus giganteus** Vahl.
Claviceps purpurea
- Elymus glauca** Buckley
Claviceps purpurea
- Festuca arundinacea** Schreb.
Claviceps purpurea
- Festuca elatior** L.
Claviceps purpurea
- Festuca ovina** L.
Claviceps purpurea
- Festuca rubra** L.
Claviceps purpurea
- Fragaria** sp.
Diderma effusum var. *reticulatum*
- Gleditsia tricanthos** L.
Linospora gleditsiae
- Glycine max** Merr.
Cephalosporium gregatum
Diaporthe phaseolarum var. *bata-tatis*
Diaporthe phaseolarum var. *sojae*
Glomerella glycines
Peronospora manshurica
Pseudomonas tabacum
Sclerotinia sclerotiorum
- Hordeum vulgare** L.
Pythium graminicola
- Hoya carnosa** R. Br.
Gloeosporium sphaerella
- Humulus lupulus** L.
Pseudoperonospora humuli
- Ipomoea batatas** Poir
Nectria ipomoeae
- Ipomoea hederacea** Jacq.
Colosporium ipomoeae
- Ipomoea pandurata** (L.) G. W. Mey.
Colosporium ipomoeae
- Linum usitatissimum** L.
Colletotrichum linicola
- Lolium perenne** L.
Claviceps purpurea
- Lonicera tatarica** L.
Herpobasidium deformans
- Melilotus** sp.
Gloeosporium trifolii
- Muhlenbergia mexicana** (L.) Trin.
Cercospora muhlenbergiae
- Panicum dichotomiflorum** Michx.
Puccinia graminis
- Phalaris arundinacea** L.
Claviceps purpurea
- Phalaris californica** Hook. & Arn.
Claviceps purpurea
- Phalaris canariensis** L.
Claviceps purpurea
- Phalaris caroliniana** Walt.
Claviceps purpurea
- Physostegia virginiana** (L.) Benth.
Puccinia physostegiae
- Picea abies** (L.) Karst.
Sphaeropsis pinastri
- Pinus ponderosa** Douglas
Septoria acicola
- Pinus strobus** L.
Phomopsis strobis
- Poa arachnifera** x **Poa pratensis**
Claviceps purpurea
- Poa compressa** L.
Claviceps purpurea
- Poa pratensis** L.
Urocystis agropyri

- Populus** sp.
Calonectria rubescens
- Populus grandidentata** Michx.
Melampsora abietis-canadensis
- Populus tremuloides** Michx.
Marssonina brunnea
- Potentilla simplex** Michx.
Frommea obtusa
- Puccinia graminis** Pers.
Darlucia filum
- Pycnanthemum pilosum** Nutt.
Puccinia angustata
- Quercus alba** L.
Chalara quercina
- Quercus borealis** Michx.
Chalara quercina
- Quercus ellipsoidalis** E. J. Hill
Chalara quercina
- Quercus imbricaria** Michx.
Chalara quercina
- Quercus macrocarpa** Michx.
Chalara quercina
- Quercus marilandica** Muench.
Chalara quercina
- Quercus muhlenbergii** Engelm.
Chalara quercina
- Quercus palustris** Muench.
Chalara quercina
- Quercus velutina** Lam.
Chalara quercina
- Rhus glabra** L.
Botryosphaeria ribis
- Rhus typhina** L.
Botryosphaeria ribis
- Ribes hudsonianum** Richards
Cronartium ribicola
- Rosa rugosa** Thunb.
Phragmidium speciosum
- Setaria glauca** (L.) Beauv.
Pythium graminicola
- Sisymbrium officinale** (L.) Scop.
Cerospora cruciferarum
- Stipa viridula** Trin.
Claviceps purpurea
Ustilago hypodytes
- Tecoma radicans** (L.) Juss.
Xenosporaella larvalis
- Trifolium pratense** L.
Sclerotium rolfsii
- Triodia flava** (L.) Hitchc.
Puccinia windsoriae
- Ulmus** sp.
Calonectria rubescens
- Vernonia illinoensis** Gleason
Puccinia vernoniae

LITERATURE CITED

1. ALLINGTON, W. B.
 1945. Wild fire disease of soybeans. *Phytopath.* 35:857-69.
2. ———, AND D. W. CHAMBERLAIN
 1948. Brown stem rot of soybean. *Phytopath.* 38:793-802.
3. ARENS, K.
 1929. Untersuchungen über Pseudoperonospora humuli (Miyabe u. Takah.), den Erreger der neuen Hopfen Krankheit. *Phytopath. Ztschr.* 1:169-93.
4. ARTHUR, J. C.
 1934. Manual of the rusts in United States and Canada. Lafayette, Indiana. 438 pp.
5. ATANASOFF, D.
 1920. Ergot of grains and grasses. USDA (mimeo.), p. 62.
6. ATKINSON, G. F.
 1897. Some fungi from Alabama collected chiefly during the years 1889-92. *Bull. Cornell Univ. (Sci.)* 3:1-50.
7. BARNETT, H. L.
 1945. New reports of Iowa fungi. *Iowa Acad. Sci. Proc.* 52:95-100.
8. EERGEY, D. H.
 1948. Manual of determinative bacteriology. Baltimore, Md. 6th Ed., p. 124.

9. BRAGONIER, W. H.
1949. Umbrella disease of *Rhus glabra* and *R. typhina* caused by *Botryosphaeria ribis*. Phytopath. 39:3. (Abstr.)
10. BUCHHOLTZ, W. F.
1938. Factors influencing the pathogenicity of *Pythium debaryanum* on sugar beet seedlings. Phytopath. 28:448-75.
11. ———
1944. Pathogenesis of *Aphanomyces cochlioides* on taproots of the sugar beet. Phytopath. 34:485-89.
12. CLINTON, G. P.
1904. North American Ustilagineae. Boston Soc. Nat. Hist. Proc. 31:329-529.
13. DAVIS, J. J.
1919. Notes on parasitic fungi in Wisconsin VI. Wisconsin Acad. Sci. Trans. 19:701.
14. DIETZ, S. M., AND R. A. YOUNG
1948. Oak wilt—a serious disease in Iowa. Iowa Agr. Exp. Sta. Bull. P91:1-20.
15. DRECHSLER, C.
1929. The beet water mold and several related root parasites. Jour. Agr. Res. 38:309-61.
16. ELLIS, J. B., AND B. M. EVERHART
1885. Enumeration of the North American Cercosporae. Jour. Myc. 1:17-24, 33-40, 49-56, 61-67.
17. ———, AND ———
1887. Additions to Cercospora, Gloeosporium, and Cylindrosporium. Jour. Myc. 3:13-22.
18. ———, AND ———
1888. Additions to Ramularia and Cercospora. Jour. Myc. 4:1-7.
19. ———, AND ———
1889. New and rare species of North American fungi. Jour. Myc. 5:145-57.
20. ———, AND G. B. MARTIN
1882. New species of North American fungi. Amer. Naturalist. 16:1001-04.
21. GAEUMANN, ERNST
1923. Beiträge zu einer Monographie der Gattung Peronospora Corda. Beitr. Kryptogamenfl. d. Schweiz 5:1-360.
22. GILMAN, J. C.
1931. First supplementary list of parasitic fungi from Iowa. Iowa State College Jour. Sci. 6:357-65.
23. ———, AND W. A. ARCHER
1929. The fungi of Iowa parasitic on plants. Iowa State College Jour. Sci. 3:299-507.
24. GOULD, C. J., Jr.
1944. The parasitism of *Glomerularia lonicerae* (Pk.) D. and H. in *Lonicera* species. Iowa State College Jour. Sci. 19:301-31.
25. GROSSENBACHER, J. G.
1909. A Mycosphaerella wilt of melons. New York (Geneva) Agr. Exp. Sta. Tech. Bull. 9:193-299.
26. ———, AND B. M. DUGGAR
1911. A contribution to the life-history, parasitism, and biology of *Botryosphaeria ribis*. New York (Geneva) Agr. Exp. Sta. Tech. Bull. 18:113-90.
27. GROVE, W. B.
1935. British stem- and leaf-fungi. (Coelomycetes) 1:181. Cambridge.

28. HENRY, B. W., C. S. MOSES, C. AUDREY RICHARDS, AND A. J. RIKER
1944. Oak wilt, its significance, symptoms and cause. *Phytopath.* 34:636-47.
29. HO, WEN-CHUN, C. H. MEREDITH, AND I. E. MELHUS
1941. *Pythium graminicola* Subr. on barley. *Iowa Agr. Exp. Sta. Res. Bull.* 287: 239-314.
30. LEHMAN, S. G., AND F. A. WOLF
1926. Soybean anthracnose. *Jour. Agr. Res.* 33:381-91.
31. LINDER, D. H.
1929. A monograph of the helicosporous fungi imperfecti. *Ann. Missouri Bot. Gard.* 16: 227-388.
32. LUCK, E. R.
1947. *Linospora gleditsiae* in Iowa. *Iowa Acad. Sci. Proc.* 54:161-67.
33. MACBRIDE, T. H., AND G. W. MARTIN
1934. *The Myxomycetes*. New York. 339 pp.
34. MIDDLETON, J. T.
1943. The taxonomy, host range and geographic distribution of the genus *Pythium*. *Mem. Torrey Bot. Club* 20:1-171.
35. MEEHAN, F., AND H. C. MURPHY
1946. A new *Helminthosporium* blight of oats. *Science* n.s. 104:413-14.
36. ———, AND ———
1949. *Septoria avenae* on oats in Iowa. *Phytopath.* 39:15. (Abstr.)
37. O'GARA, P. J.
1915. New species of *Colletotrichum* and *Phoma*. *Mycologia* 7:38-41.
38. PECK, C. H.
1880. Report of the botanist. *New York State Mus. Nat. Hist. Rept.* 33:11-49.
39. PETHYBRIDGE, G. H., AND H. A. LAFFERTY
1918. A disease of flax seedlings caused by a species of *Colletotrichum* and transmitted by infected seed. *Sci. Proc. Dublin Soc.* n.s. 15:359-84.
40. SACCARDO, P. A.
1882-1928. *Sylloge Fungorum*. Padua 24 vol.
41. SCHWARZE, C. A.
1917. The parasitic fungi of New Jersey. *New Jersey Agr. Exp. Sta. Bull.* 313:1-226.
42. SEAVER, F. J.
1909-11. The *Hypocreales* of North America I-IV. *Mycologia* 1:41-76, 1:177-207, 2:48-92, 3:207-25.
43. STEVENS, F. L.
1931. A comparative study of *Sclerotium rolfsii* and *Sclerotium delphinii*. *Mycologia* 23:204-22.
44. TIFFANY, L. H.
1948. Further observations on *Claviceps purpurea*. *Iowa Acad. Sci. Proc.* 55: (in press).
45. WEBER, G. F.
1922. I. Speckled blotch of oats caused by *Leptosphaeria*. *Phytopath.* 12:450-70.
46. WEHMEYER, L. E.
1933. The genus *Diaporthe* Nitschke and its segregates. *Univ. Michigan Studies* 9:1-349.
47. WELCH, A. W.
1945. *Pythium* root necrosis of oats. *Iowa State College Jour. Sci.* 19:361-99.

48. ————
1947. A study of soybean diseases and their control. Iowa Agr. Exp. Sta. Rpt. 1946-47:170-71.
49. ————, AND J. C. GILMAN
1948. Hetero- and homo-thallic types of *Diaporthe* on soybeans. *Phytopath.* 38:628-37.
50. WINTER, G.
1885. *Fungi novi Missouriensis*. *Jour. Mycol.* 1:121-26.
51. WOLF, F. A.
1917. A squash disease caused by *Choanephora cucurbitarum*. *Jour. Agr. Res.* 8:319-28.
52. YOUNG, P. A., AND H. E. MORRIS
1927. Sclerotinia wilt of sunflowers. *Montana Agr. Exp. Sta. Bull.* 208:3-32.
53. YOUNKIN, S. G.
1938. *Pythium irregulare* and damping off of watermelons. *Phytopath.* 33:596.

THE PRESENCE OF WATER IN OXYGEN-CARRYING COBALT COMPOUNDS

HARVEY DIEHL AND JOHANNA HENN

Department of Chemistry, Iowa State College

Received April 22, 1949

The unique property of the bivalent cobalt derivative of disalicylaldehydendiimine of reversibly absorbing and releasing oxygen has been studied by Diehl and co-workers (1). The quantity of oxygen absorbed by this material and compounds related to it corresponds to one molecule of oxygen per two cobalt atoms. The maroon-colored, deoxygenated compound is paramagnetic having a susceptibility corresponding to one unpaired electron. On absorbing oxygen, which is also paramagnetic but with two unpaired electrons, the material becomes black and diamagnetic. The process of oxygenation and deoxygenation is completely reversible, being induced by only mild changes in temperature or oxygen pressure. The heat of reaction is of the order of 20,000 calories per mole.

It is evident that the oxygen molecule must be attached in the oxygenated compound to each of two cobalt atoms. It becomes of interest to learn if this is a result of a fortuitous disposition of the cobalt atoms in the crystal lattice or if perhaps the compound is not binuclear in character, with the orientation of the cobalt atoms arranged by the existence in the molecule of a bridging group which occupies at once a coordination position of each of two cobalt atoms. The quadridentate, chelating, organic molecule occupies four coordination positions about the cobalt atom, the bridging group could occupy the fifth position common to two cobalt atoms, and the two sixth positions would then be open for the oxygen molecule to slip in forming a second, peroxo bridging group.

From an electronic composition standpoint such a view is sound. Thus, to the twenty-five electrons of bivalent cobalt are added eight electrons by the four non-ionic bonds with the organic group, and two by the bridging molecule. The odd electron of the total of 35, a $4p^1$, is left unpaired. The addition of the oxygen molecule brings in one unpaired electron for each cobalt atom, filling out the $4p^6$ shell and completing the krypton structure of 36 electrons.

The hydroxyl group, a common bridging group in binuclear cobalt chemistry, is ruled out for only two hydrogen ions are liberated in the formation of the compound as would be expected. Water seems to be the only other bridging group possible although such water bridges have not been reported (2). Some qualitative evidence exists

for the presence of this water. In anhydrous ethanol, the oxygen-carrier is not formed but inactive orange and green compounds are produced which pass over to the maroon oxygen-carrier on treatment with water. Indeed the orange body can be observed momentarily as a short-lived precursor to the oxygen-carrier in water during its formation in water.

This bridging water molecule, however, is tightly bound in the compound, for the oxygen-carrier may be heated to 180° without loss in weight; around 190° salicylaldehyde begins to distil from the material. Direct analysis of the material fails to yield positive proof. The material is insoluble in all solvents but pyridine and chloroform from which it yields inactive products with solvent of crystallization. The compound must be analyzed as first prepared without recrystallization and unfortunately there is enough variation from batch to batch to cast just sufficient uncertainty on even the most accurately performed analyses to render questionable a factor of 9 (half a water per cobalt) in a molecular weight of 325. Nor can the molecular weight of the compound be determined cryoscopically. Using the only two solvents available the boiling points are depressed rather than elevated, probably because of the expulsion of water from the molecule by the preferentially coordinated solvent. Nor is the freezing point method more successful. Stable freezing temperatures are not found, again probably because of the expulsion of water.

The fact that pyridine expels the water from the molecule finally suggested an elegant direct proof of the presence of the water—namely, distillation of the water from the compound with pyridine and titration of the collected water with the Karl Fischer reagent.

A variation on this method of attack proved less successful: that is, the direct titration of the water in a pyridine solution of the compound with the Karl Fischer reagent employing the "Dead Stop End-point" as applied to the Karl Fischer titration by Wernimont (3).

Both methods were adopted and used on the parent oxygen-carrying compounds, on three substituted oxygen-carriers, and on the free Schiff's base, disalicylaethylenediimine, from which the parent compound is derived. The results are summarized in Table 1. The distillation-titration procedure yielded results quite close to the calculated values for a half molecule of water per cobalt atom. The direct titration procedure gave high results. It would naturally be expected that the iodine in the Karl Fischer reagent would react with the double bonds in the compound. That such a reaction occurs is evidenced by the results on the Schiff's base alone. The results of this experiment are not in good agreement, the extent of the reaction being small and apparently dependent on certain conditions which were not controlled suitably. With the oxygen-carrying compounds, this side reaction apparently took place to a lesser extent, as might be expected where the Schiff's base is attached firmly to the metal atom.

The slightly negative result on the one analysis of the Schiff's base by the distillation method is explained by a slight hydrolysis of

the Schiff's base by the water present in the pyridine and methanol used (blanks). In general the results on the oxygen-carriers are slightly low. A slight hydrolysis by the water of the cobalt-Schiff's base to give cobalt-salicylaldehyde and ethylenediamine would account for this.

In any case all four of the oxygen-carrying compounds investigated contained water in amounts corresponding to one molecule of water per two cobalt atoms. This is substantial evidence for a binuclear structure of these materials and hence for the more involved binuclear nomenclature employed in Table 1.

EXPERIMENTAL WORK

DISTILLATION AND TITRATION APPARATUS

The distillation apparatus consisted of a 500 ml., 2-necked round bottom flask. The sample and solvent were introduced through the side neck, which was closed by a ground glass plug and opened only briefly when necessary. A distillation column about 30 cm. in length and 1.5 cm. in diameter, packed with glass beads, was placed on the center neck of the flask. This column carried a distilling head with thermometer and was attached to a water-cooled condenser. The latter was connected through an adapter to the center neck of a 1 liter,

TABLE 1
SUMMARY OF RESULTS OF THE DETERMINATION OF WATER IN OXYGEN-CARRYING
COBALT COMPOUNDS

Compound	Oxygen-Carrying Capacity		Water Content		
	Theory Per Cent	Found Per Cent	Theory Per Cent	Found by Direct Titration Per Cent	Found by Distillation Per Cent
Bi-(disalicylaethylenediimine)- μ -aquo-dicobalt (Parent Compound, Co-Ox)	4.79	4.60	2.69	3.00 3.03 3.10	2.41 2.56 2.59
Disalicylaethylenediimine (Schiff's base of parent compound)				.92 1.80	— .22
Bi-(di-[2-hydroxy-3-methoxy- benzal]ethylenediimine)- μ - aquo-dicobalt (3-Methoxy Co-Ox)	4.17	4.02	2.47	2.85 2.90	2.28 2.29 2.46
Bi-(di-[2-hydroxy-3-ethoxy- benzal]ethylenediimine)- μ - aquo-dicobalt (3-Ethoxy Co-Ox)	3.80	3.52	2.38	2.84 2.84	2.33 2.42
Bi-(di-[2-hydroxy-3- <i>n</i> -butoxy- benzal]ethylenediimine)- μ -aquo-dicobalt (Co-Ox SS)	3.41	2.99	2.22	2.47 2.65	2.29 2.48

3-neck round bottom flask, which served as a receiving flask. The other two side necks of this flask were closed by ground glass plugs during the distillation. All connections in the apparatus were thus ground glass joints. The mixture in both the distilling flask and the titration vessel was agitated by means of a magnetic stirrer.

Following the distillation the titration was carried out as indicated in the 1 liter, 3-neck receiving flask, two Machlett dispensing burets being used, their tips entering the flask through the side necks through rubber stoppers. When the end-point was determined potentiometrically two platinum electrodes were introduced through the central neck, the platinum being fused to glass tubes which passed through a rubber stopper.

DEAD STOP END-POINT

In certain experiments this was used. The circuit consisted of a 1.5 v. dry cell, a 50 ohm variable rheostat functioning as a voltage divider, a Leeds and Northrup galvanometer with lamp and scale and two platinum electrodes.

PREPARATION OF COMPOUNDS AND REAGENTS

The compounds analyzed were various products prepared earlier by Diehl and co-workers (1). The material was deoxygenated at 130° in a vacuum. After cooling to room temperature in a vacuum, the sample was weighed rapidly, and quickly introduced into the reaction vessel. Because of the hygroscopic character of some of the materials, speed at this point was essential. The oxygen-carrying capacity of the materials used was determined on a sample similarly prepared by subjecting it to oxygen at 100 p.s.i. pressure. The sample was removed and quickly weighed. This served as a measure of the purity of the materials.

Anhydrous methyl alcohol was prepared by distillation from magnesium turnings treated with a little mercuric chloride.

Anhydrous pyridine was prepared by distillation from freshly broken lumps of potassium hydroxide.

The Karl Fischer reagent was prepared in two liter quantities according to the directions of Smith, Bryant, and Mitchell (4) by dissolving 169.4 g. (0.33) mole of resublimed iodine in a mixture of 538 ml. (3.3 mole) of anhydrous pyridine and 1334 ml. of anhydrous methanol. This mixture was then cooled in chopped ice and 128 g. (1 mole) of liquid sulfur dioxide added cautiously. This reagent was stored and delivered from a Machlett Buret.

STANDARDIZATION OF THE KARL FISCHER REAGENT

The water content of the anhydrous methanol was first determined by introducing into the titration vessel 10.0 ml. of anhydrous methanol and titrating with the Karl Fischer reagent. Then 10.0 ml. of a standard

water solution in the same anhydrous methanol was introduced into the titration flask and titrated similarly. The blank on the anhydrous methanol was subtracted and the strength of the Karl Fischer reagent calculated in grams of water per milliliter. The end-point adopted was a dark orange which could be distinguished from the yellow background of the solution only with some difficulty. The blank on the methanol was quite small, 1.10 ml. of Karl Fischer reagent per 10.0 ml. of methanol. The strength of the Karl Fischer reagent was of the order of 3 mg. of water per ml. The reagent was standardized daily.

Alternatively the Karl Fischer reagent was standardized potentiometrically. An excess of the reagent was added and back-titrated with a standard water in methanol solution delivered from a second dispensing buret. As usual blanks were run.

DIRECT TITRATION PROCEDURE

A weighed sample of approximately 2 g. in powdered form was quickly introduced into a dry, clean 1 liter, 3-neck titration vessel with two dispensing burets already in place. The sample was introduced through the central neck and followed immediately by 25.0 ml. of absolute methanol and 25.0 ml. of anhydrous pyridine. The central neck was then closed by the stopper carrying the platinum electrodes. The mixture was then agitated for an hour at room temperature by a magnetic stirrer. At the end of this interval the water was titrated electrometrically by adding an excess of Karl Fischer reagent and back-titrating with the water-methanol solution.

DISTILLATION PROCEDURE

The clean, dry distillation and receiving flasks were connected as described above and 100 ml. of pyridine introduced into the distilling flask. A volume of 75 ml. of it was distilled over as quickly as possible and discarded by disconnecting the receiving flask for as short a time as possible. The distillation flask and contents were cooled to room temperature and a sample of oxygen-carrying material weighing about 2 g. was introduced quickly followed by 25 ml. of methanol. The mixture was then stirred for an hour after which another 100.0 ml. of pyridine was introduced. Heat was then applied and the distillation carried out as quickly as possible, taking not more than 20 minutes. As soon as the distillation was finished, the receiving flask was removed and the stopper with the dry platinum electrodes quickly inserted into the center neck. The glass plugs in the two other necks were next removed and the receiving flask quickly slipped over the rubber stoppers on the tips of the two dispensing burets, thus converting the receiving flask into a titration flask. The titration was then carried out using the dead-stop and end-point described above. Visual titrations gave the same results within experimental error.

LITERATURE CITED

1. DIEHL, AND CO-WORKERS
Iowa State College Jour. Sci. 21:271, 278, 287, 311, 316, 326, 335; 22:91, 110, 126,
129, 141, 150, 165.
2. GMELINS HANDBUCH DER ANORGANISCHEN CHEMIE
1930. 58B, Verlag Chemie, Berlin.
3. WERNIMONT, AND HOPKINSON
1943. Ind. Eng. Chem., Anal. Ed. 15:272.
4. SMITH, BRYANT, AND MITCHELL
1939. Jour. Amer. Chem. Soc. 61:2407.

THE REACTION OF FERROUS IRON WITH NIOXIME

JOHN MATHEWS, JR. AND HARVEY DIEHL

Department of Chemistry, Iowa State College

Received April 22, 1949

In the first report of his epochal researches on the metallic derivatives of the 1,2-dioximes, Tschugaeff (1) in 1905 noted that the dioximes yielded intensely colored, purple, soluble compounds with ferrous iron. Although nickel, platinum, palladium, cobalt and even copper gave well defined crystalline products, the ferrous derivatives of various 1,2-dioximes proved recalcitrant, and in only one case, that with methylglyoxime and pyridine, could a product of sufficient purity be secured to make an analysis fruitful. The composition of this material corresponded to $\text{Fe}(\text{HM})_2\text{py}_2$, adopting for the dioxime and pyridine the symbols H_2M and py . In a later paper (2) Tschugaeff returned to this reaction of ferrous iron and discovered that ammonia or an amine was necessary for production of the purple color. With such a base present, color could be recognized with as little as 1 part of iron in 10,000,000. In addition to being a sensitive qualitative test, the reaction was suitable for the determination of iron colorimetrically.

During the succeeding three decades research on the dioximes was focused by the analytical chemists on dimethylglyoxime and its remarkably specific reaction with nickel and palladium. The inorganic chemists also were active. During the 1920's the extensive works of Thilo and of Cambi on the numerous, and complicated derivatives of cobalt appeared. The early thirties yielded the work of Pfeiffer which established the five-membered ring structure of the nickel compound by chemical evidence based on the earlier reorganization by Meisenheimer of the relations of the stereoisomers of the dioximes. During this period the work of Sugden on the *cis-trans*-isomerism observed with the nickel derivatives of unsymmetrical dioximes which established the planar structure of the nickel and palladium compounds also appeared. The knowledge of the structure and analytical applications of these materials was adequately reviewed in 1940 (3). The dimethylglyoxime-ferrous reaction was mentioned several times during this period of thirty years, principally when someone made the hardly novel discovery that it was easy to mistake traces of iron for nickel. The ferrous-dioxime reaction really needs reinvestigation, but recent work in the field has taken a new turn—water soluble dioximes have now become available.

Aqueous, alkaline solutions of dimethylglyoxime are not stable,

and the numerous attempts to use them are ample testimony to the inconvenience of preparing alcohol solutions in industrial laboratories and to the uncertainty of contaminating precipitates by the addition of an excess of a water insoluble reagent. Although 1,2-cyclohexanedione-dioxime was reported to be water soluble and very sensitive for nickel as early as 1924 by Wallach (4), it is doubtful if much was ever prepared before the study of its synthesis by Diehl and co-workers in 1945 (5). Later improvements by Hach and Diehl (6) have made the reagent available at moderate cost.¹ 1,2-Cyclohexanedione-dioxime has been given the common name *Nioxime*. The uses of nioxime in the analytical chemistry of nickel and palladium have been investigated carefully by Voter, Banks, and Diehl (7, 8). The reaction of ferrous iron with nioxime naturally becomes of interest, and is the subject of this paper.

More recently an exhaustive investigation of the possibilities of determining iron by the ferrous-dioxime reaction was made by Griffing and Mellon (9); four dioximes (dimethylglyoxime, diethylaminodimethylglyoxime, nioxime and alpha-furildioxime) were studied and a careful investigation made into the factors affecting the stability of the color and into the interfering substances. The conditions required for stabilizing the color (excess of hyposulfite and excess of amine) were so drastic that all of the common cations except the alkali metals and ammonium interfere either because of precipitation or reaction. Although the sensitivity of the colors compared favorably with that of the ferrous-*o*-phenanthroline reaction, Griffing and Mellon were left only lukewarm toward the dioximes as colorimetric reagents for iron.

EXPERIMENTAL WORK

Reagents

A 0.01 M aqueous solution of nioxime was used in the work described in this paper. Such solutions have been shown to not change on standing (7). A 0.01 M solution of iron was prepared by dissolving a weighed quantity of pure, electrolytic iron in hydrochloric acid and diluting to volume in a volumetric flask. Since this solution contained both ferrous and ferric iron it was necessary to use a reducing agent to insure that all iron was in the ferrous form. The reducing agent finally chosen was sodium hyposulfite ($\text{Na}_2\text{S}_2\text{O}_4$) because of its reducing action in basic solutions. This is the reducing agent preferred by Griffing and Mellon (9). A solution was prepared by dissolving 10 g. of sodium hyposulfite in a mixture of 100 ml. of reagent grade ammonium hydroxide and 50 ml. of water. Such a solution will keep for several days. In developing the color 3 ml. portions of this solution were used for samples containing 1 mg. or less of iron followed by dilution to 50 ml. The ethylenediamine was purified by distillation over calcium oxide, keeping the fraction boiling at 116–117°. The hydrazine hydrate was the 85 per cent aqueous solution obtained from Eastman Kodak Company.

¹ Available from the Hach Chemical and Oxygen Company, Ames, Iowa.

Reaction of Ferrous Iron and Nioxime

Ferrous iron and nioxime solutions when mixed gave a yellow or brown color in concentrations of 0.01 M. Addition of sodium hydroxide to such mixtures resulted in the formation of a black precipitate, undoubtedly ferrous hydroxide. If instead of sodium hydroxide, ammonium hydroxide or an amine were used, a deep red or violet color was developed. The order of mixing was then, the iron solution, nioxime, the amine, and finally sodium hydroxide to give the necessary pH for complete formation of the complex. Ammonia, hydrazine, hydroxylamine, ethylenediamine, benzidine, and hexamethylenetetramine produced the characteristic deep red or violet color. Certain other aliphatic amines did not work well owing to their insolubility in aqueous solutions. Pyridine produced the red color in dilute solutions, but on standing a red precipitate formed in 20-30 minutes.

The sensitivity of the ferrous-nioxime reaction is about the same as that of dimethylglyoxime. One part of iron in 18,000,000 being the lower limit for the ferrous-nioxime-ethylenediamine complex. The sensitivity is not sensibly different with ammonia or the other amines.

Spectral Distribution and Effect of pH

Spectral distribution curves for the ferrous-nioxime complexes with ammonia, hydrazine, and ethylenediamine were secured at an iron concentration of 2×10^{-4} (Fig. 1).

Square cells having a 1.000 cm. optical path were used in a Beckman model DU spectrophotometer for all of the measurements. A 5m μ spectral band width was used, and readings were taken every 10 m μ except at points of minimum transmittancy where 5 m μ intervals were employed. The ammonia complex was prepared by adding 2 ml. of 0.01 M nioxime to 1 ml. of 0.01 M iron solution. To this was then added 3 ml. of the ammonia-hyposulfite solution, and after fifteen minutes the solution was diluted to 50 ml. The cells were rinsed twice with small portions of this solution, and then filled with the solution. The complexes with the other amines were prepared by adding an excess of solid sodium hyposulfite to 1 ml. of 0.01 M iron. This was followed by an excess of nioxime and 1 ml. of hydrazine hydrate or ethylenediamine. Sodium hydroxide was added to obtain the desired pH, and the solution was diluted to 50 ml.

Each of the complexes was also measured at 540 m μ with a spectral band width of 5 m μ for iron concentrations from 1×10^{-5} to 20×10^{-5} . Conformity to Beer's law was indicated by the straight lines obtained when $\log I/I_0$ values were plotted against concentration. Molecular extinction coefficients were calculated, and found for ferrous-nioxime ammonia, 6988, for ferrous-nioxime hydrazine, 8639, and for ferrous-nioxime ethylenediamine, 6490. These results are shown graphically in Figure 2.

Quite early in the course of these investigations it became apparent that pH played an important role in the development of the character-

istic red or purple color. The addition of an excess of acid to one of the colored materials resulted in a change from the red or purple to a yellow. The effect of changing pH was studied by first forming the violet complex of ferrous-nioxime-ethylenediamine, and then adding hydrochloric acid dropwise. The pH was determined with a pH meter, and a sample was measured for transmittancy at 540 m μ . From Figure

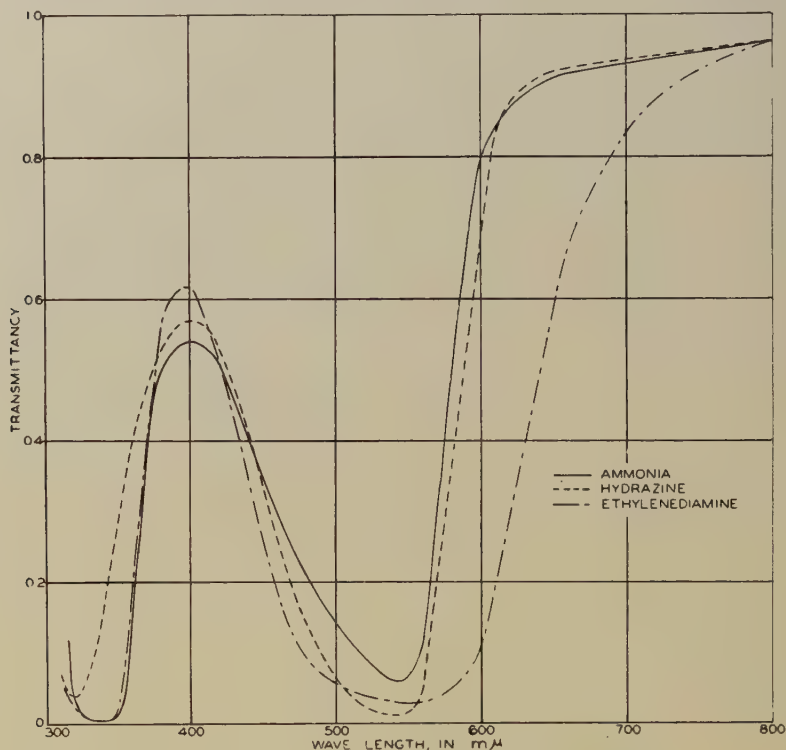


FIG. 1.—Transmittancy of ferrous-nioxime-amine complexes.

3 it is quite evident that the color is not fully developed below a pH of 9.5.

Composition of Compound

The ratio of ferrous iron to nioxime was studied according to the method of continuous variations. Job (10) proposed this method in the study of ammonia complexes, and Vosburgh and Cooper (11) further expanded the application of this method to more complex systems. A series of solutions was made up in which the molar concentration of nioxime was varied from 0 to 2×10^{-4} M. In each solution of the series

the total molar concentration of ferrous iron plus nioxime was kept fixed at 2×10^{-4} M. These solutions were made up using the ammonia-hyposulfite solution. Readings of I/I_0 were taken at 540 m μ and $\log I/I_0$ was plotted against mole fraction of nioxime. The points corresponding to 0 and 1 mole fraction nioxime were connected by a straight line, and the variance of each of the other solutions from this line measured. This variance was then plotted against the mole fraction of nioxime (Fig. 4). The results of three experiments are presented together with the composite average of the experiments. The mole fraction corres-

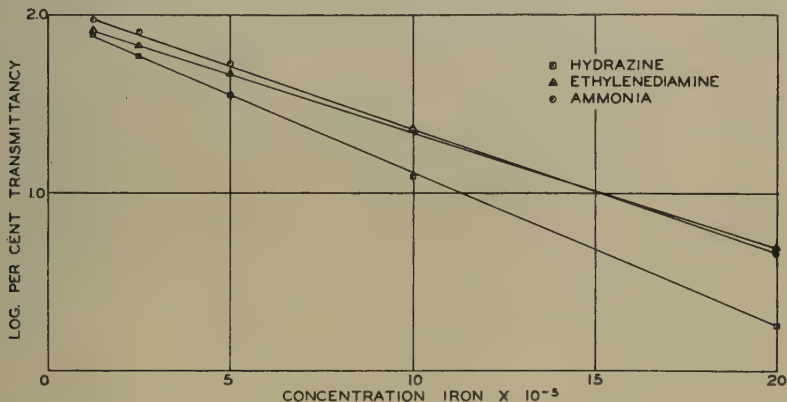
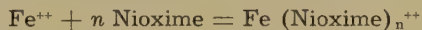


FIG. 2.—Logarithm of transmittancy as a function of concentration of ferrous-nioxime-amine complexes.

ponding to the point of intersection was then determined, and this value used in the equation

$$n = \frac{x}{1 - x}.$$

The value of x from the graph was 0.67 which gave a value of 2.03 for n . This n is the number of molecules of nioxime associated with one iron according to the equation



The ratio of ferrous iron to ammonia was studied in a similar manner. As before the total concentration of the variables was kept fixed at 2×10^{-4} M while keeping an excess of nioxime present. The results in this case were not as striking as in the study of the iron to nioxime ratio. The colors were weak, and precipitates formed in a short time. From the few readings obtained the number of ammonia molecules per iron was greater than one, but no definite ratio could be established.

The nature of the charge on the complex was of interest since it

would possibly shed some light on the problem of structure. A cell was constructed to study the migration of the colored complexes while under the effect of a direct electrical current. This cell consisted of a central chamber with two agar filled U tubes leading from it. The outer arms of these U tubes contained 1 M potassium chloride. Platinum electrodes were immersed in these solutions, and a direct current of 10 milliamperes applied. Under the influence of this current the

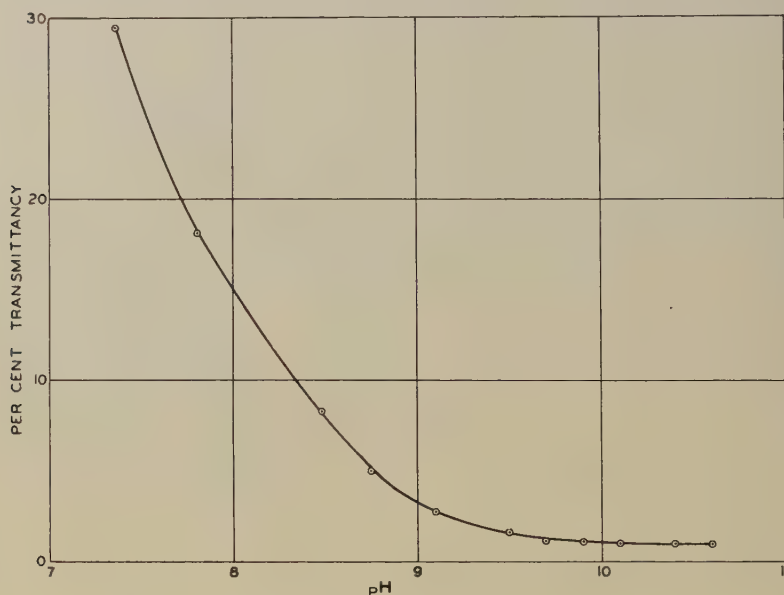


FIG. 3.—Stability as a function of pH.

complexes with ammonia and ethylenediamine were observed to move from the central chamber down into the U tube carrying the anode. Upon reversal of the current the purple color moved in the opposite direction. This evidence indicates that these ferrous-nioxime complexes behave as anions.

Oxidation-Reduction Indicator

Charlot (12) found that the ferrous-dimethylglyoxime complex functioned as an oxidation-reduction indicator in basic solutions, passing reversibly from red to yellow on oxidation. Thus, in the titration of hyposulfite with potassium ferricyanide the ferrous-dimethylglyoxime-ammonia complex is quite a satisfactory indicator. The ferrous-nioxime complex was found to have this same property. The complex with hydrazine was not satisfactory, owing probably to oxidation of the hydrazine by the ferricyanide. On the other hand, the complexes with ammonia

and ethylenediamine functioned very well, passing from red or purple to yellow when an excess of the oxidizing agent was added. The color change is quite sharp, as little as one-half drop of 0.1 M ferricyanide being sufficient to cause the color change at the equivalence point. Good warning of approach to the end point was observed, the ferricyanide apparently oxidizing the indicator followed by a slower reduction of the indicator by the small excess of hyposulfite present. Preliminary

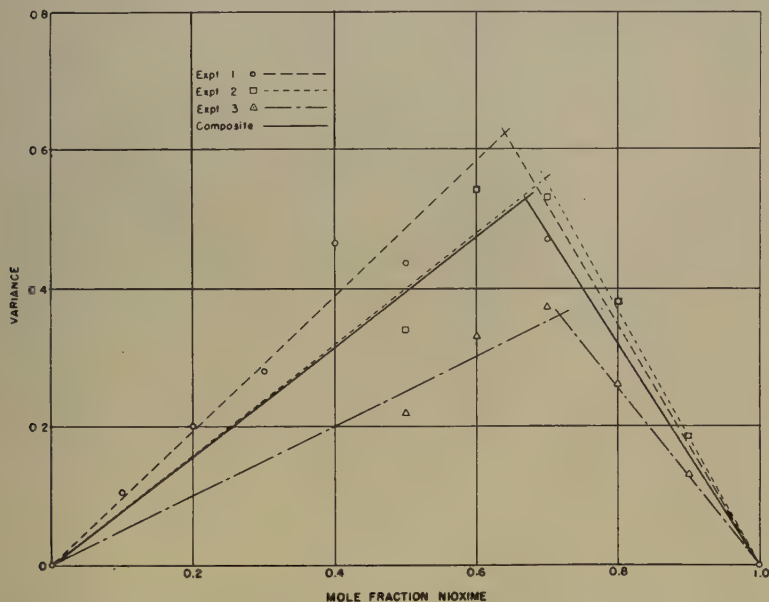


FIG. 4.—Application of method of continuous variations to the ferrous-nioxime-ammonia reaction.

estimates of the standard reduction potential of these couples show them to be surprisingly low, in the neighborhood of -0.65 v.

Reversible Oxygenation and Deoxygenation

When exposed to air overnight the ammonia complex underwent a decided change in color. From the intense red noted upon first mixing the reagents the color changed slowly to a yellow. The same change in color was noted with the hydrazine and ethylenediamine complexes, although not at such a rapid rate as was found in the case of the ammonia complex. When kept tightly covered no such color change was noted. When kept in covered cuvettes the transmittancy did not change noticeably in three hours indicating sufficient stability for most spectrophotometric work. By passing oxygen broken up into fine bubbles through a solution of the ethylenediamine complex it was

possible to effect the change from red to yellow in a matter of five to ten minutes. The ammonia complex changed even quicker, and the change was shown for the hydrazine and hexamethylenetetramine complexes also. In the case of the ethylenediamine complex this color change could be reversed by passing nitrogen previously purified by bubbling through alkaline pyrogallol through the yellow solution. The purple color was restored although not so strong as it had been before the conversion to the yellow form. Nitrogen straight from the tank was without effect in restoring the purple color, probably owing to a small content of oxygen. An attempt was made to pump the oxygen from the solution, but at a pressure of 15–20 mm. no restoration of color was observed.

DISCUSSION

The work described above shows that the ferrous-nioxime complexes consist of one atom of iron holding two molecules of nioxime, and that ammonia or amine is also involved. Feigl and Suter (13) have shown recently that the yellow palladium compound of dimethylglyoxime is soluble in alkali, and have isolated a sodium-palladium-dimethylglyoxime compound in which the dimethylglyoxime functions as a dibasic acid. It is apparent from the migration experiment that in the ferrous-nioxime complex the dioxime is also functioning as a dibasic acid. The situation is somewhat different, however, for the coordination number of iron is six and two amine molecules are needed to complete the structure.

The high pH required for color formation indicates that the ammonia molecules are not very tightly bound in the complex. The loss of red color in acidic or weakly basic solution points to the relative ease of removal of these coordinated molecules. The same change in color occurs when oxygen is passed through the solution. It is probable that the ammonia or amine linkages are ruptured and replaced by coordinate linkages to oxygen. This compound also exhibits slight instability shown by the gradual restoration of the purple color when the slight partial pressure of oxygen in the usual state is lowered by sweeping with pure nitrogen. This sensitivity toward oxygen has been noted previously (14, 15), and various conditions proposed for securing the stability desired for such colored systems. It is believed however that this is the first time that the reaction with oxygen has been shown to be reversible. This is rather remarkable in view of the fact that no simple, water soluble iron compounds have been shown previously to have this ability to reversibly add and lose oxygen.

The ability of these compounds to function as oxidation-reduction indicators is of interest since a basic solution is required. Willard and Manalo (16) have studied a group of these oxidation-reduction indicators for reactions in basic solution, and these iron-nioxime complexes may prove valuable additions to this field.

LITERATURE CITED

1. TSCHUGAEFF
1905. Z. anorg. Chem., 46:144.
2. ———, AND ORELKIN
1914. Z. anorg. Chem., 89:401.
3. DIEHL
1940. "The Applications of the Dioximes to Analytical Chemistry," G. Frederick Smith Chemical Company, Columbus, Ohio.
4. WALLACH
1924. Ann., 437:148.
5. RAUH, SMITH, BANKS, AND DIEHL
1945. Jour. Org. Chem., 10:199.
6. HACH, BANKS, AND DIEHL
To appear in Organic Syntheses.
7. VOTER, ———, AND ———
1948. Anal. Chem., 20:458.
8. ———, ———, AND ———
1948. Anal. Chem., 20:652.
9. GRIFFING AND MELLON
1947. Anal. Chem., 19:1017.
10. JOB
1928. Ann. chim., 9:113.
11. VOSBURGH AND COOPER
1941. Jour. Amer. Chem. Soc., 63:437.
12. CHARLOT
1939. Bull. soc. chim., 6:970.
13. FEIGL AND SUTER
Jour. Chem. Soc., 1948:378
14. KOENIG
1922. Chimie and industrie, 7:55.
15. SLAWIK
1912. Chem. Ztg., 36:54.
16. WILLARD AND MANALO
1947. Anal. Chem., 19:167.

AN IMPROVED HIGH FREQUENCY CONDUCTIMETRIC TITRATION APPARATUS

ROBERT J. BEVER, CARL E. CROUTHAMEL AND HARVEY DIEHL

Department of Chemistry, Iowa State College

Received April 22, 1949

The use of conductance measurements with alternating current of high frequency to follow change in the composition of solutions has been investigated by Blake (1, 2) and by Jensen and Parrack (3). The apparatus described by these workers is based on the principle of loading the tank circuit of an oscillator by changing the dielectric of the condensers or the inductance of the coil by change in the composition of a solution placed within them.

In the apparatus presented in this paper the oscillator, cell, and measuring device are completely independent units. Any stable high frequency oscillator of a few watts output can be readily adapted to the rest of the circuit so that commercially available oscillators, with their inherently high stability, can be used. The oscillator and metering circuit are thus isolated from the titration cell and are not subjected to fumes, humidity, and occasional accidents with solutions. Operation is particularly convenient and the sensitivity can be varied to fit the demands of the problem.

ELECTRICAL CIRCUIT

The electrical circuit (Fig. 1) consists of an oscillator, a reaction cell, a transmitter type inductance coil, a detector and bucking voltage unit, and a vacuum tube voltmeter. The oscillator, an R.C.A. Master Oscillator (MI-19427), and the tube voltmeter, an Advanced Voltohymst, are standard commercial instruments. The other units were assembled in the laboratory.

The reaction cell, the transmitter coil and the coaxial connecting cables make up the resonant circuit. A 6006 tube and its cathode circuit make up the detector and the bucking voltage unit. Inductances L_1 and L_2 are to prevent the r.f. from circulating in the filament transformer. Condenser C_3 is used to keep the r.f. from the batteries by offering a low impedance path to ground. R_1 , R_2 , and R_3 in the cathode circuit are used to control the cathode current through the tube and R_2 also furnished the d.c. voltage for the vacuum tube voltmeter. The high voltage across the transmitter coil requires 400 volts from a battery source to satisfactorily buck the rectified oscillator voltage. Two 300 volt Mini-Mak batteries No. 493 can be used successfully as the current drawn is very slight.

The resonant circuit shown in Figure 1 consists of two main components, the inductance coil (L_3 and L_4) and the cell. The inductance coil was mounted on a ceramic form 10 cm. in diameter with 36 turns, space wound, of No. 13 B. and S. silver plated wire. The length of the winding was 15 cm. It is necessary to have one variable tap for the oscillator input in order to tune the coil to the resonance peaks. The size of the wire and the dimensions of the coil are secondary factors and can be varied over a moderately wide range.

The cell (Fig. 2) is 5.5 cm. in diameter, holding about 100 to 200 ml. of solution in the working range. A 60/50 standard taper joint was used in the construction of the cell. An inlet for the buret which

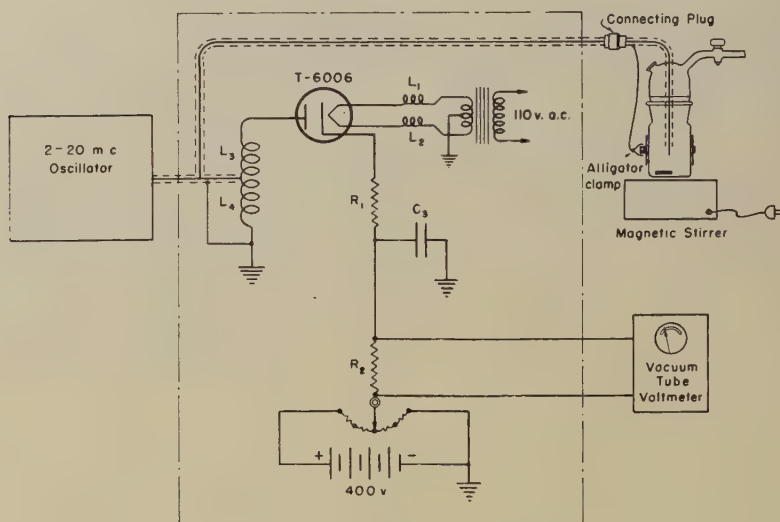


FIG. 1.—Electric circuit of high frequency conductimetric titration apparatus.

R_1 100,000 ohms R_2 2 megohm variable
 R_3 10 megohms C_1 0.001 μf

also served as a gas outlet and a stopcock for a gas inlet were provided in the top of the cell. A shielded coaxial cable enclosed in a glass tube extended into the cell and was fused to a platinum wire. The platinum wire was sealed into the tip of the tube and about one centimeter came into direct contact with the solution. A grounded copper shield on the outside of the cell completed the conducting path of the high-frequency current through the solution. The solution was stirred by means of a magnetic stirrer. It was important that the tip of the platinum wire be at least 4.5 cm. above the rotating magnet to prevent interference in the detecting circuit.

The electrical equivalent of the cell and transmitter coil is shown in Figure 3. R_1 and C_1 represent the cell where R_1 is the resistance

of the solution and C_1 is the capacitance of the cell. C_2 is the capacitance of the coaxial cable which is large compared to C_1 . The oscillator input is adjusted on the transmitter coil (L_3 and L_4) so as to give a maximum reading in the detector circuit.

It was originally noticed that when the approximate 200 volts produced by the oscillator on a loaded circuit was used in a titration,

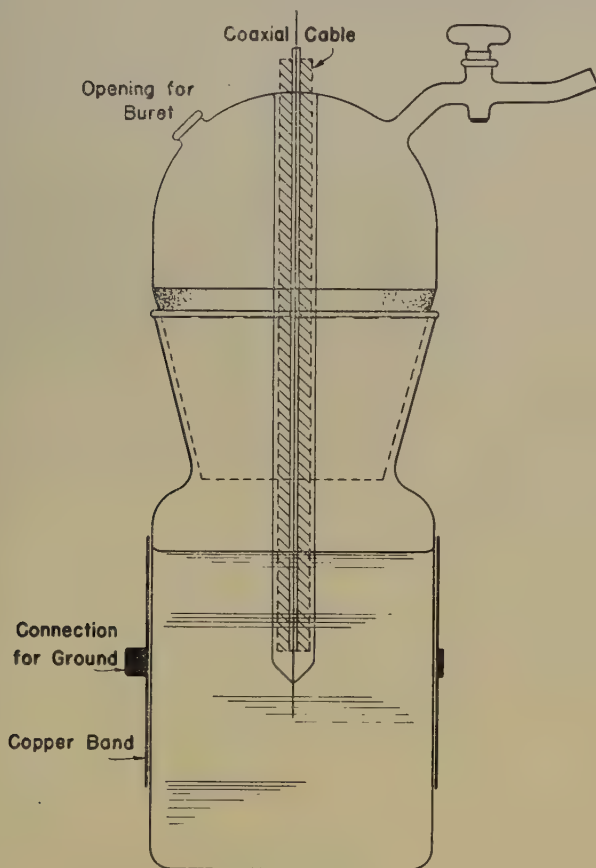


FIG. 2.—Titration cell.

that the change in voltage was so small that it was difficult to read accurately the voltage on the 300 volt scale. In order to use the entire scale of the meter and still have the same change in voltage, a detector and bucking voltage circuit was added (Fig. 1). Thus, where previously during a titration, a 10 volt change occurred which represented only 0.03 per cent of the entire scale now, with all but 10 volts of the

200 volts bucked out, the readings could be taken on the 10 volt scale and represent a change of 100 per cent of the total scale. This greatly increased the accuracy and the sensitivity of the apparatus.

Several adjustments must be made when setting up the apparatus for the first time. One of these is the length of the exposed platinum electrode in the cell; this controls the sensitivity of the cell, and must be adjusted to give the optimum sensitivity. The best length of the electrode for the cell (Fig. 2) was 1 cm. This was found by starting with a length of about 3 cm. and securing voltage readings with varying concentrations of potassium chloride. For this length, the readings were

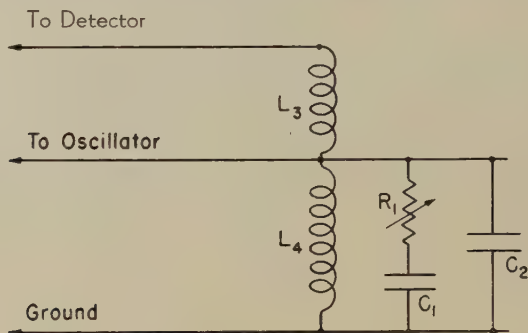


FIG. 3.—Equivalent circuit of inductance coil, titration cell and connecting coaxial cable.

quite scattered. About 0.5 cm. was cut from the electrode and test repeated. This process was continued until the points plotted gave a curve whose points were within the accuracy desired.

The oscillator was set at some frequency around 20 megacycles and the tap on the transmitter coil was adjusted for maximum voltage output. The maximum sensitivity can be obtained by tuning either the oscillator or the transmitter coil. Once having the system tuned to resonance it was found to be more convenient to vary the oscillator controls for peaking on the resonant curve before every titration rather than changing the transmitter coil tap. Peaking the voltage was done after the solution had been added to the reaction cell. Tuning by varying the oscillator controls does vary the frequency, but slight variations in frequency have little effect on the output of the oscillator.

The case of the vacuum tube voltmeter was placed on rubber mounts and thus insulated from the rest of the apparatus.

Some typical loading curves for a solution containing an electrolyte are shown in Figure 4. Various types of loading curves may be obtained depending upon the concentration used and the conductance of the ions present. Figure 5 shows the result of 3.3 p.p.m. of potassium chloride diluted with water from 150 ml. to 250 ml.

The following explanation has been proposed for the voltage changes under various conditions. From the equivalent circuit (Fig. 3) it is seen that the transmitter coil is divided so as to form an auto-transformer made of L_3 and L_4 . Consider that X_c , the reactance of the condenser, is equal to $1/wC$ and that X_{L_4} , the reactance of the inductance coil L_4 is equal to wL_4 , where w is $2\pi f$. Then I_c is proportional to wC and I_{L_4} is proportional to $1/wL_4$. Keeping in mind that frequency is expressed as $f = 1/2\pi\sqrt{LC}$, we notice (Fig. 4) that the voltage decreased when potassium chloride was added to the solution.

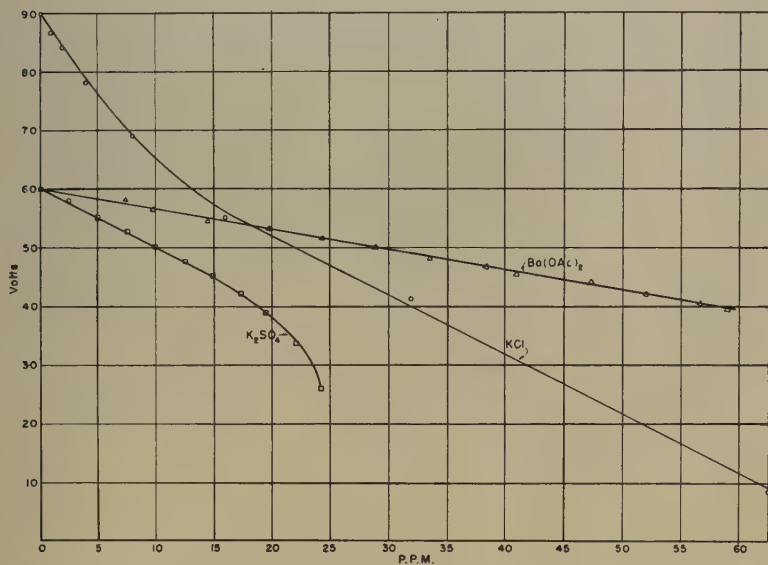


FIG. 4.—Variation of voltmeter reading with concentration.

The addition of ions to the solution increases the capacitance of the solution. This produces a decrease in I_{L_4} and thus a decrease in the voltage read.

The same explanation can be used for Figure 4 in which an electrolyte is progressively diluted, the capacitance thus decreased, the current in the inductance coil correspondingly increased, and voltage as read on the voltmeter increased.

These two explanations may be combined to explain the titration of potassium sulfate with barium acetate (Fig. 5).

It was expected that the heat generated by the passage of the current would increase the temperature sufficiently to alter the conductance. Experiment showed that in sixty minutes a solution was warmed 5.8° resulting in a decrease in the voltage reading of 2.5 volts.

Thus, titrations carried out rapidly would not be influenced significantly by this effect. For longer periods a correction could be applied.

CONDUCTIMETRIC TITRATIONS

To test the apparatus conductimetric titrations of potassium sulfate with barium acetate and of fluoride with thorium nitrate were carried out.

The end-points in the case of the titration of sulfate were eminently satisfactory in concentrations higher than 40 p.p.m. of sulfate (about 0.00045 M). As with conductimetric titrations at lower frequencies, the

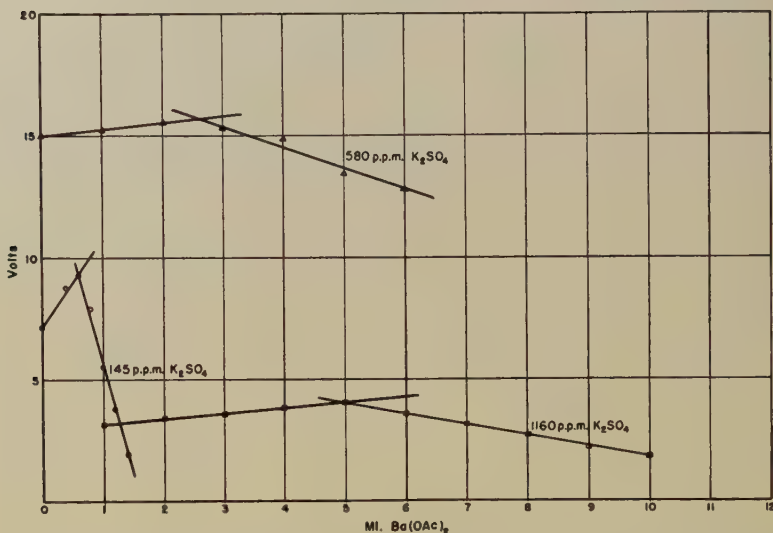


FIG. 5.—Titration of potassium sulfate with barium acetate. Sulfate concentration above 40 p.p.m.; end-point stoichiometric.

data before and after the end-point were satisfactory and the results stoichiometric up to 0.05 N sulfate. No doubt even more concentrated solutions could be titrated successfully.

At concentrations below 40 p.p.m. the results on varying the quantity of sulfate were not in proportion to the amount taken but depended on the time taken for the titration. At these low concentrations a precipitate of barium sulfate did not form and it appeared that the rate of growth of the barium sulfate particles was involved. In Figure 6 are plotted data showing the character of the titration curves obtained with the same amount of sulfate but carried out at different rates.

The same phenomenon was observed in the titration of fluoride with thorium nitrate. Below 25 p.p.m. of fluoride the results are not stoichiometric; above this amount the results were satisfactory.

RATE OF PRECIPITATION OF BARIUM SULFATE

After it was realized that a time factor was involved in the conductimetric titration of sulfate it became of interest to determine the time required for the establishment of equilibrium after mixing sulfate and barium ions.

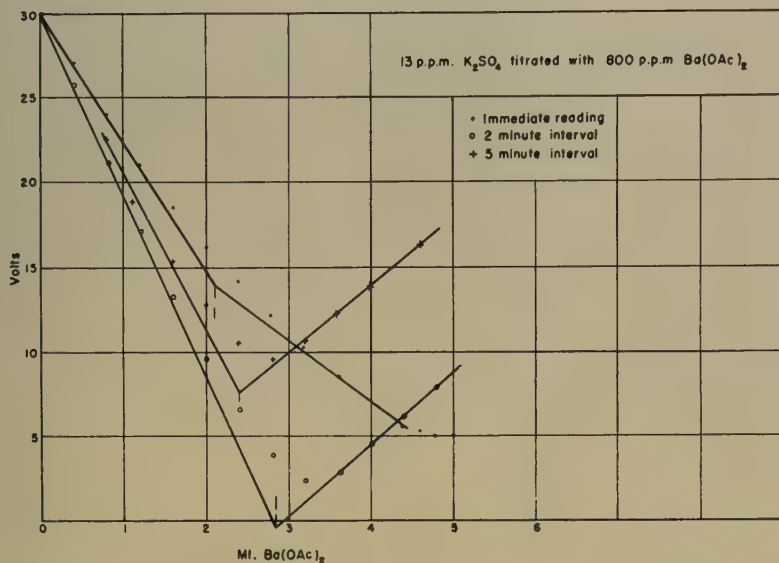


FIG. 6.—Titration of potassium sulfate with barium acetate illustrating non-stoichiometric character of end-point in dilute solution.

A solution of potassium sulfate was placed in the cell, the apparatus adjusted, and a solution of barium acetate added. The voltage reading was taken immediately and at five minute intervals thereafter. An induction period is evident in each of the curves. Data for two ratios of sulfate and a theoretical treatment of the data are given in the paper by Bever, Duke and Diehl (4).

ACKNOWLEDGEMENT

The authors wish to express their appreciation to the Standard Oil Company of Indiana for financial aid for this work.

LITERATURE CITED

1. BLAKE, J.
1945. Sci. Instruments, 22:174.
2. ———
1946. Chemistry and Industry, No. 3, 28.
3. JENSEN AND PARRACK
1946. Ind. Eng. Chem., Anal. Ed., 18:595.
4. DUKE, BEVER, AND DIEHL
1949. Iowa State College Jour. Sci., 23:297.

THE RATE OF PRECIPITATION OF BARIUM SULFATE

FREDERICK R. DUKE, ROBERT J. BEVER, AND HARVEY DIEHL

Department of Chemistry, Iowa State College, Ames, Iowa

Received April 22, 1949

In the preceding paper measurements of the rate of precipitation of barium sulfate using a modified high-frequency conductivity instrument have been reported (1). A sigmoid-type curve characteristic of processes with an induction period is obtained (Fig. 1).

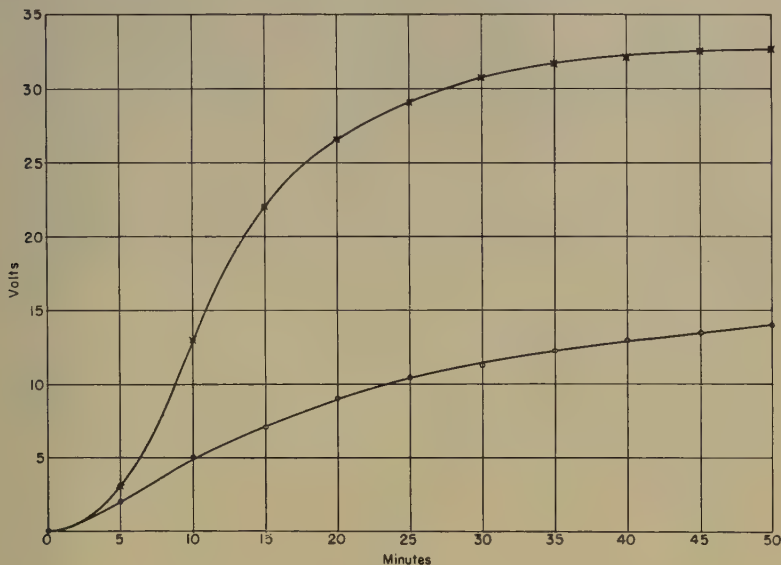


FIG. 1.—The rate of precipitation of barium sulfate.

Previous attempts to interpret the kinetics of barium sulfate precipitation are chiefly those of von Weimarn (2) whose work leads to an empirical set of precipitation rules. He was unable to formulate any sort of exact treatment for lack of accurate rate data. With more satisfactory experimental data now available it becomes of interest to develop a more complete and precise theory to account for the observed rates of precipitation of barium sulfate.

THEORY

The rate of precipitation of barium sulfate was assumed to be proportional to the product of the surface area and the barium ion and the sulfate ion concentrations:

$$\text{I} \quad \frac{dP}{dT} = kS[\text{Ba}^{++}] [\text{SO}_4^{--}]$$

where P is the number of moles of precipitate per unit volume, k the specific rate constant and S the surface area of the precipitate. The surface, in turn, is:

$$\text{II} \quad S = n4\pi r^2$$

where n is the number of particles of precipitate, and r the radius of the particles. Further,

$$\text{III} \quad n = \frac{P (\text{Mol. Wt. BaSO}_4)}{\rho (4/3\pi r^3)}$$

where ρ is the density of the barium sulfate. In other words, the number of particles is the total volume divided by the volume of each particle. Combining II and III,

$$\text{IV} \quad S = \frac{3P (\text{Mol. Wt. BaSO}_4)}{\rho r}$$

The radius, r , may be cancelled out as done in the combined equations if the particles are uniform in size. The unknown r is eliminated in the following way: It is assumed that the ionic agglomerate capable of growing to crystal size is the ion pair. The number of ion pairs which may grow is set by the following equilibrium:



and by the original barium and sulfate ion concentrations, $[\text{Ba}^{++}]_0$ and $[\text{SO}_4^{--}]_0$. Thus,

$$\text{V} \quad n = k[\text{Ba}^{++}]_0[\text{SO}_4^{--}]_0$$

Combining I, IV and V, the final equation is obtained:

$$\frac{dP}{dt} = k \left[\frac{3P (\text{Mol. Wt. BaSO}_4)}{\rho} \right]^{2/3} \left[4k[\text{Ba}^{++}]_0 [\text{SO}_4^{--}]_0 \right]^{1/3} [\text{Ba}^{++}] [\text{SO}_4^{--}]$$

Combining all constants

$$\text{VI} \quad \frac{dP}{dt} = k' [\text{Ba}^{++}]_0^{1/3} [\text{SO}_4^{--}]_0^{1/3} P^{2/3} [\text{Ba}^{++}] [\text{SO}_4^{--}]$$

TEST OF THE THEORY

Using the plane-surface mirror technique, normals were drawn to the curve at various points (Fig. 1). The negative reciprocal of the

slope of the normal gives the instantaneous rate of precipitation, $\frac{dP}{dt}$

at that point. P was evaluated by considering the asymptotically approached maximum in the voltage curve to be the point of complete precipitation and assuming a linear function relating voltage to quantity of precipitate formed. Suspended barium sulfate was shown to have no conductivity. Knowing P and the original concentrations of Ba^{++} and SO_4^{--} , the concentrations of these ions at any time were evaluated. These values were used with equation VI to calculate k' (Table 1).

TABLE 1
CALCULATION OF k' , PRECIPITATION RATE CONSTANT

$\frac{dP}{dt}$	$P^{2/3} \times 10^4$	$[\text{Ba}^{++}] \times 10^4$	$[\text{SO}_4^{--}] \times 10^4$	$k'[\text{Ba}^{++}]_0[\text{SO}_4^{--}]_0$	$k' \times 10^9$
Upper curve					
0.....	0	1.95	1.4		
0.166.....	.58	1.95	1.4	.108	
0.62.....	2.3	1.95	1.4	.102	
2.2.....	12	1.55	1.0	.121	3.6
2.3.....	15.5	1.3	0.8	.145	
1.1.....	21.5	0.95	0.4	.128	
0.52.....	25	0.75	0.2	.138	
0.34.....	25	0.70	0.13	.136	
Lower curve					
0.....	0	1.0	1.4		
0.46.....	10	0.60	1.00	.08	
0.42.....	10	0.58	0.98	.07	3.3
0.14.....	13	0.20	0.60	.09	

DISCUSSION

As will be seen from Table 1 fairly good agreement was obtained for the value of k' for the two runs, at different initial concentrations of barium ion. It was assumed that the ion pair is the precursor of the crystal and that the number of ion pairs and hence the number of particles of precipitate is set by the original concentrations of barium and sulfate ions. It is assumed also that all of the particles grow at uniform rate. Since a fairly constant value of k' was obtained these assumptions appear justified. A microscopic examination of barium sulfate precipitated this way shows that the particles are all of uniform size (Fig. 2).

Since the number of ion pairs increases with decreasing dielectric constant, the number of particles will be larger and the particle size less when barium sulfate is precipitated from a solvent such as mixed water-alcohol. It is likely that the number of ion pairs increases as the temperature decreases. Thus smaller particles should be expected under given conditions when obtained from cold solutions. Smaller particles should be obtained from concentrated solutions than from dilute. All of these conclusions are borne out by experience, but it is planned to continue these studies to obtain more quantitative information.

This treatment is rather insensitive to the size of the original ionic agglomerate, which may turn out to be an ionic triplet or larger agglomerate when more data are obtained.



FIG. 2.—Barium sulfate crystals. $\times 100$.

LITERATURE CITED

1. BEVER, CROUTHAMEL, AND DIEHL
1949. Iowa State College Jour. Sci., 23:289
2. VON WEIMARN
1926. Chem. Rev., 2, 217

HISTOLOGICAL DEVELOPMENT OF "ACCESSORY BLADE" AND ASSOCIATED ABNORMALITIES IN MAIZE¹

JOHN E. SASS AND G. F. SPRAGUE²

*From the Botany and Plant Pathology Section and the Agronomy Section,
Iowa Experiment Station*

Received June 10, 1949

Morphological characters of the seedling are useful in some genetic studies in maize. Large populations can be grown in relatively small space and with little labor, and the early expression of suitable seedling characters permits early classification of a population. Some seedling characters are included in a summary of heritable characters in maize by Emerson, Beadle, and Frazer (2). Very little histological information is available concerning unusual characters of the embryo, seedling, or mature plant. Bryan and Sass (1) described a leaf abnormality that may well be re-examined in the embryo and seedling. Many other embryo and seedling characters that have been noted by breeders deserve morphological study.

One of the selfed progenies from FPI No. 4565, introduced from Chosen (Korea) in 1931, has been used in the present studies. In this stock, some seedlings become contorted during emergence. Such seedlings resemble the twisted seedlings (tw) described by Kvakan (3). Some seedlings bear a supernumerary "strap" leaf, dorsal to the first leaf. The coleoptile may develop a green, leafy blade on one margin, and the first two foliage leaves may bear accessory laminae. Displacement of leaves from normal phyllotaxy has also been noted.

Seedling abnormality is inherited as a simple recessive, but linkage relations have not been established. The proposed symbols Ab, ab, are derived from "accessory blade," one of the expressions of the abnormality. Classified on the basis of gross morphology, segregating populations of the homozygous recessive type regularly exhibit deficient ratios of mutant type. The histological data furnish a possible explanation for the deficient ratios; however the present report deals primarily with the developmental histology of the described abnormalities.

¹Contribution from the Iowa Agricultural Experiment Station in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Journal Paper No. J-1575 of the Iowa Agricultural Experiment Station, Project 182.

²Research Professor, Botany and Plant Pathology Section, Iowa Agricultural Experiment Station, Agent, Division of Cereal Crops and Diseases; and Senior Agronomist, Division of Cereal Crops and Diseases, Collaborator Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station, respectively.

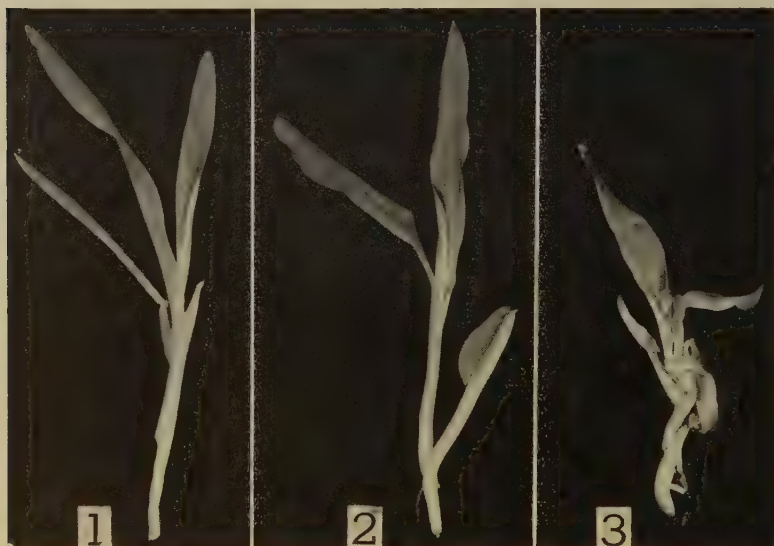
MATERIALS AND METHODS

Collections of kernels made at the stated intervals after pollination were processed, sectioned and stained by the dioxan-normal butyl alcohol process described by Sass (4). The method used for the study of mature, dormant embryos, to be described in detail in a later report, consists essentially of soaking the kernels under controlled conditions, removing the embryo, and processing as above. The desired parts of seedlings were prepared by the usual paraffin method.

OBSERVATIONS

Seedlings begin to exhibit abnormalities as soon as the coleoptile has grown to full height above the soil line. Leaves fail to emerge from some coleoptiles, and such seedlings shrivel and die in about a week. Some seedlings produce one foliage leaf of normal size and structure, but no additional leaves emerge. As the normal seedlings of a population put forth successive leaves, the extent of suppression of leaf formation becomes evident in the abnormal seedlings. All gradations from leafless coleoptiles to normal plants occur in a population.

The strap leaf emerges soon after the first foliage leaf. When the seedling has two emerged leaves, the narrow, green strap leaf may be almost as long as the first leaf (Fig. 1). The green leafy blade that develops on some coleoptiles is also well defined at this age. (Fig. 2).



FIGS. 1-3.—Seedlings of maize 15 days after emergence. FIG. 1.—Seedling with two normal foliage leaves and a well-developed "strap" leaf, on left side in illustration. FIG. 2.—Seedling with two normal foliage leaves. The coleoptile has a green leaf-like blade along one edge. FIG. 3.—Seedling with highly contorted leaves and coleoptile.

Seedlings that have much coalescence between members become contorted in varying degrees (Fig. 3). The survival of such seedlings is roughly proportional to the degree of malformation; however no accurate data are available concerning the longevity of abnormal seedlings. The previously mentioned aberrations of phyllotaxy and the accessory laminae on the seminal leaves also require quantitative study.

The first histological evidence of abnormal organogeny is the initiation of the strap leaf. This is detectable in embryos collected fifteen days after pollination. In typical embryos of that age, the plumule, encased by the coleoptile, consists of the dome-shaped apical meristem, the small sub-terminal primordium of the second leaf, and the larger first leaf. The coleoptile is still open on the anterior side (Figs. 9 and 10). Some embryos have a zone of deeply stainable cells at the coleoptile node, on the anterior side of the embryo. This zone is the place of initiation of the strap leaf (Fig. 10).

Twenty days after pollination, a distinct primordium is evident at the base of the coleoptile (Figs. 4 and 5). This primordium resembles a leaf primordium in transverse and longitudinal aspects, and in its method of growth by meristematic activity of its margin. A procambium strand connecting the primordium and the axis is evident in twenty-five-day-old embryos (Fig. 6). The strap leaf may be attached on one side of the free arc of the axis (Fig. 11), or the attachment may extend across the arc. Figures 11 and 12 show a strap-leaf primordium at the base and at the free upper portion, respectively. This primordium has a length of 96μ .

Continued growth of the strap leaf, confined between the coleoptile and the expanding first foliage leaf, commonly results in folding of one or both edges of the strap leaf (Figs. 7, 14, and 16). Figure 16A shows the section of the strap leaf 190μ above the section shown in Figure 16. Procambium strands become well defined in the strap leaf in thirty days. Further development follows the pattern of a foliage leaf.

In some thirty-day-old embryos the strap leaf primordium develops ridged corrugations, and does not produce a leafy lamina. Figure 15 shows a section taken 60μ above the section shown in Figure 18. Another thick, crenate primordium, sectioned near its base, is shown in Figure 17.

The presence of the strap leaf may be associated with the inhibition of the formation of seminal leaves. Thirty days after pollination, normal embryos have three seminal leaves, and in some embryos a very small primordium of the fourth leaf may be present. An embryo that has a strap leaf may have three seminal leaves (Fig. 14); however such embryos most commonly have two leaves (Fig. 13), and in some embryos only one seminal leaf is present (Fig. 16). These illustrations represent progressively earlier suppression of leaf formation during embryo development.

The relative positions of successive seminal leaves is abnormal in some embryos. In Figure 20, the first leaf is in normal position. The second leaf is on the same side of the axis as the first leaf, a displacement

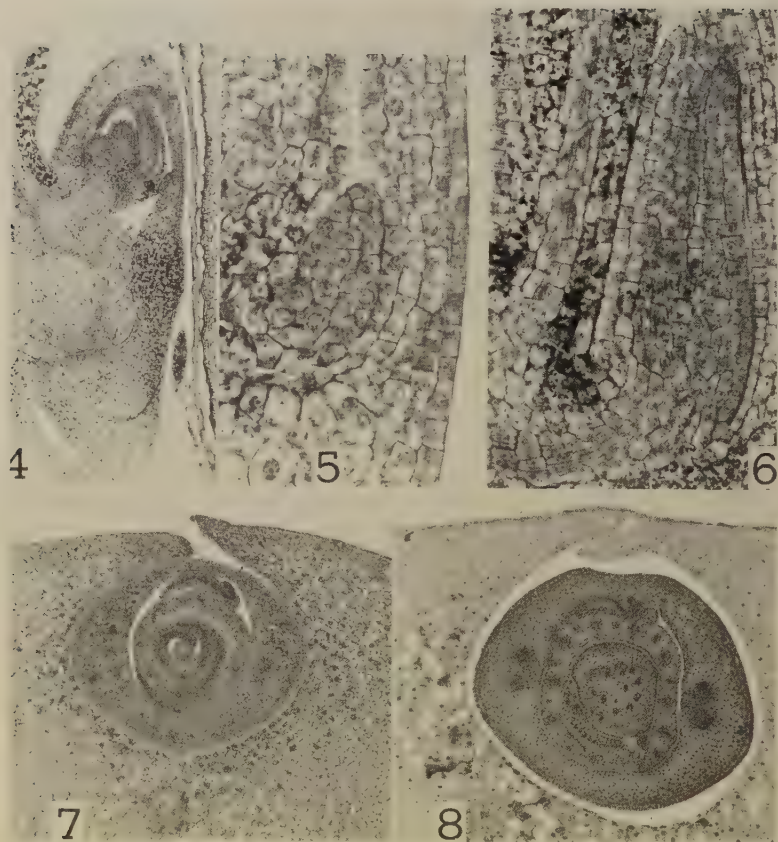


FIG. 4.—Plumule-radicle axis in kernel, 20 days after pollination. The primordium of the strap leaf is indicated by the arrow. 50x. FIG. 5.—Detail of strap leaf 20 days after pollination. 280x. FIG. 6.—Strap leaf 25 days after pollination. 280x. FIG. 7.—Cross section of plumular axis 30 days after pollination. Three foliage leaves and a reflexed strap leaf are present. 42x. FIG. 8.—Cross section of plumular axis of embryo extracted from mature, dormant kernel. Extensive fusion of leaves and coleoptile is evident. 42x. (See Figs. 9-29 for identification of parts.)

of 180 degrees. This places the second leaf directly above the first, a condition that is strikingly evident in plants in the field.

Abnormal development of the scutellum occurs in this stock of maize. In a normal embryo the anterior edges of the scutellum overlap and enclose the axis (Figs. 7, 8, and 14). In abnormal embryos, meristematic activity of the edges of the scutellum may be inhibited, whereas the mass of the scutellum continues to enlarge. The malformed scutellum thus fails to envelop the more or less normal plumule-radicle axis (Figs. 19, 21, and 22).

The most extreme malformation found in this stock involves the scutellum, the coleoptile, and the seminal leaves of the same embryo. Fusion of the coleoptile with a malformed foliage leaf may occur, associated with suppression of further leaf initiation, and also associated with the abnormal scutellar development described above. Figure 22 shows an embryo that has only one foliage leaf, developed in the form of a sheath. At a comparable level, a normal leaf has a well developed lamina with rapidly growing, overlapped edges. Abnormal extension of the leaf sheath accounts for the tubular appearance of the emerging plumule of some plants, for which the term "onion leaf" has been used. In the embryo shown in Figure 22, the leaf is confluent with the coleoptile in two regions. This coalescence makes it difficult for the leaf to emerge from the coleoptile and accounts for the contorted condition of some seedlings. It is possible that such seedlings do not emerge from the soil in the conventional field plantings.

Abnormal acceleration of meristematic activity occurs on the margins of the coleoptile of some embryos. Normally, the anterior edges of the coleoptile come into contact and cease growth twenty days after pollination. In abnormal seedlings, one edge may become meristematic and develop a leaf-like lamina. Figures 23, 24, and 25 show an embryo sectioned at three levels. At the upper level, (Fig. 23), the coleoptile is open, and one edge has developed an involute blade that has the typical vascularization and tissue systems of a leaf blade. One foliage leaf is evident at this level. At the level of the stem tip, (Fig. 25), the coleoptile exhibits the normal closure, and the large foliage leaf is adnate to the coleoptile. The primordium of the second foliage leaf has developed on the stem. An intermediate level (Fig. 24) shows the partial adnation of the foliage leaf and the coleoptile. The leafy edge of the coleoptile develops chlorophyll after emergence, but it does not grow beyond the relative size shown in Figure 2.

Thirty-five days after pollination, an additional abnormality becomes evident in some embryos. The first seminal leaf, which may be normal in other respects, may bear a blade-like outgrowth on its inner (ventral) surface (Fig. 27). This "accessory blade" arises by the reactivation of a vertical strip of tissue, which functions like the marginal meristem of a growing leaf. The free upper portion of the accessory blade is shown in Figure 27, and the attachment to the first leaf at a lower level is shown in Figure 27A. The same embryo also has a strap leaf on the side toward the scutellar edges.

Mature, dormant embryos exhibit the foregoing abnormalities in varying degrees and combinations. Normal embryos of this line have five foliage leaves during dormancy. The presence of a strap leaf may be associated with a reduction in the number of foliage leaves, displacement of phyllotaxy, and adnation of leaves with each other and with the coleoptile (Fig. 26).

The external appearance of seedling abnormalities has been described earlier in this paper. The histological details of seedling abnormali-

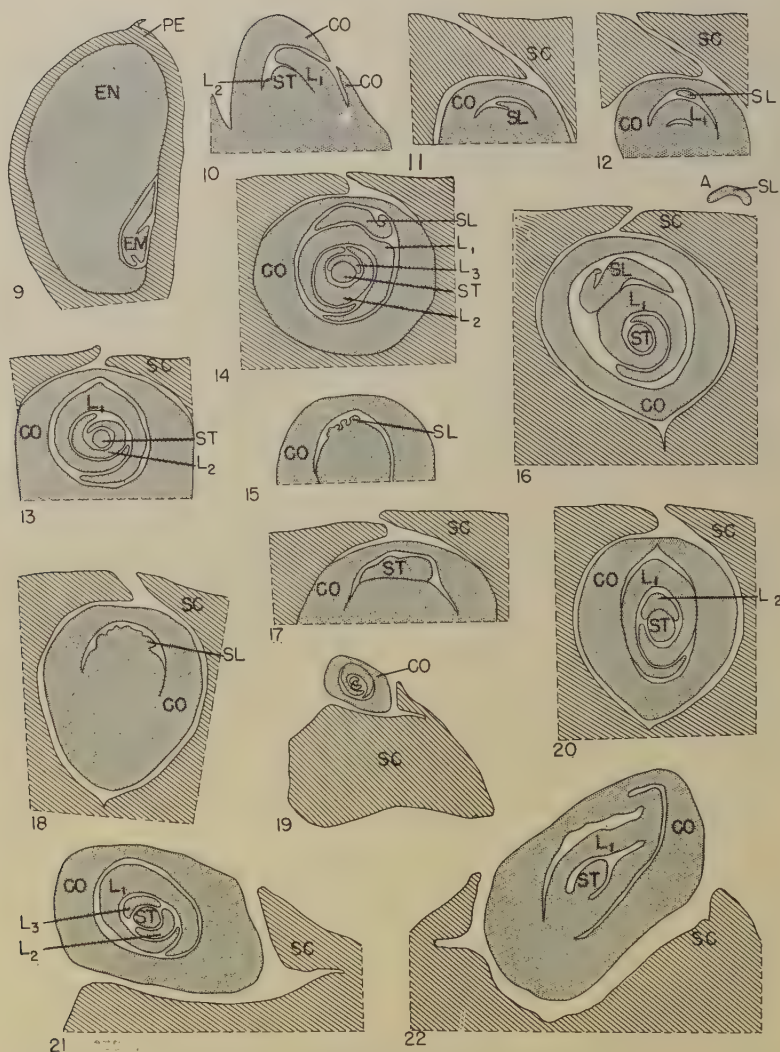


FIG. 9.—Median longitudinal section of kernel showing relative size of the embryo 15 days after pollination. 7x. FIG. 10.—Plumule of 15-day embryo, arrow indicates place of initiation of strap leaf. 33x. FIG. 11.—Transverse section of coleoptile node, with strap leaf partly free from the axis, 25 days. 33x. FIG. 12.—Free tip of strap leaf above node of first foliage leaf, 25 days. 33x. FIG. 13.—Section at level of stem tip, showing two normal foliage leaves, 30 days. 33x. FIG. 14.—Strap leaf and three normal seminal leaves, 30 days. 33x. FIG. 15.—Corrugated primordia in the position where strap leaf may occur, 30 days. 33x. FIG. 16.—Strap leaf and only one seminal leaf present at 30 days. The upper end of strap leaf shown in transverse section at A. 33x. FIG. 17.—An exceptionally thick, crenate primordium in position of strap leaf, 30 days.

ties represent further development of the conditions that were established during embryogeny. Three weeks after emergence from the soil, normal seedlings of this stock commonly have seven or eight emerged leaves. Only the two basal leaves, which are seminal leaves, were found to have abnormalities. Figure 29 illustrates coalescence between the first and second leaves. A distorted accessory blade occurs at the region of coalescence, and one margin of the first seminal leaf is folded inward. In another seedling, a section cut a considerable distance above the stem tip (Fig. 28) shows two contorted accessory laminae on the tubular first leaf. The second leaf is aborted on one margin and has three blades on the other margin. The subsequent leaves seem to be normal. The classification and incidence of the types and degrees of abnormality, and the longevity of the abnormal seedlings require further study.

DISCUSSION

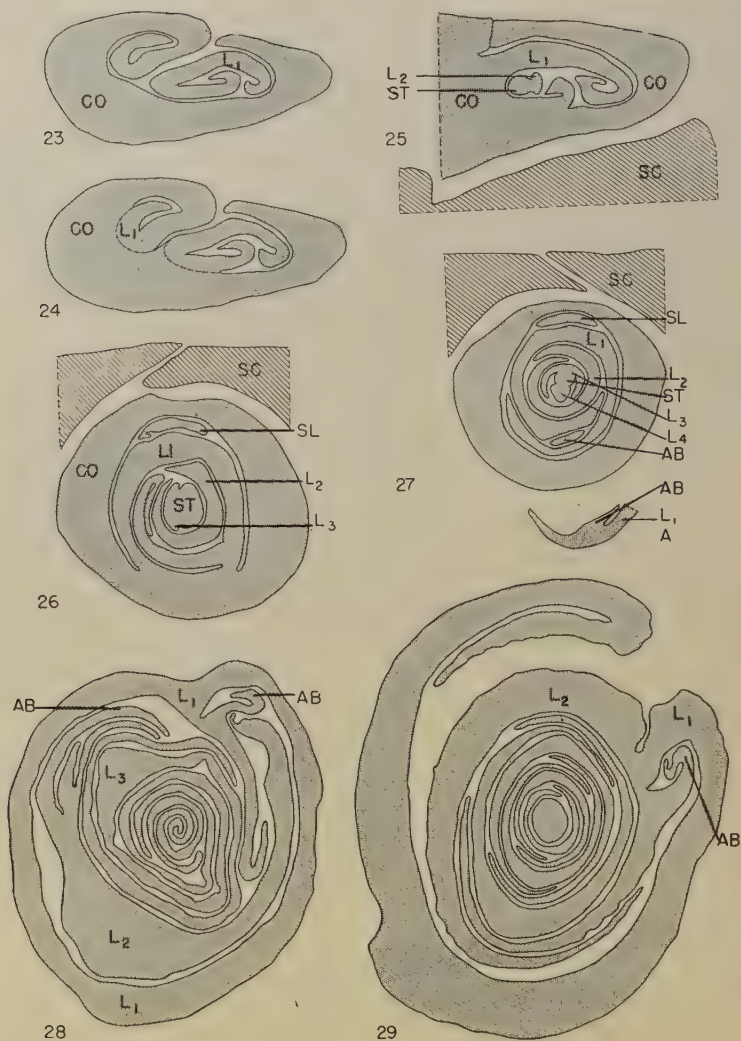
The morphological abnormalities of this stock of maize are the result of either suppression or hyperactivation of meristems, involving the marginal and basal meristems of foliar organs, as well as the massive apical meristems of the axis. There is no consistent relation between the category of the organ involved and the nature of the aberration. The apical meristems and the margins of the scutellum exhibit only suppression, the margin of the coleoptile is subject only to hyperactivity, and the marginal meristems of the foliage leaves may have either suppression or hyperactivity. The controls that normally initiate and terminate meristematic activity, and govern the orderly sequence of organogeny, are obviously out of balance. The available evidence gives no clue to any physiological basis for these abnormalities.

The mode of inheritance of the diverse abnormalities will be clarified by further study of criteria of classification. There is little doubt that in conventional field plantings many seedlings do not emerge from the ground and are missed in classification. Short-lived seedlings may also be missed. There is evidence that some embryos may not emerge from the kernel, and thus escape detection. Further embryological studies now in progress will afford a more complete classification of populations and permit genetic analysis.

SUMMARY

A stock of maize derived from an introduction from Chosen (Korea), exhibits morphological abnormalities of the embryo and seedling. The

33x. FIG. 18.—Section 60 μ below Fig. 15. FIG. 19.—Section of entire embryo showing relative size of plumule and malformed scutellum, 30 days. 13x. FIG. 20.—Embryo with two successive leaves on the same side of the axis, 30 days. 33x. FIG. 21.—Detail of plumule and aborted edges of coleoptile. 33x. FIG. 22.—Coalescence between coleoptile and first leaf. Embryo has only one leaf. The scutellar edges are aborted, 30 days. 33x. (Legend: PE, pericarp; EN, endosperm; EM, embryo; ST, stem; CO, coleoptile; SC, scutellum; SL, strap leaf; AB, accessory blade; L₁, L₂, L₃, first, second, and third foliage leaves, respectively.)



FIGS. 23, 24, 25.—Successive sections of plumule showing involute leafy blade of coleoptile, coalescence of first leaf with coleoptile, and presence of only two seminal leaves; 30 days. 33x. FIG. 26.—Plumule of mature, dormant embryo with strap leaf and with accessory blade on first seminal leaf. 33x. FIG. 27.—Strap leaf and accessory blade of 35-day embryo. FIGS. 28, 29.—Sections of two seedlings, 21 days after emergence. Accessory blades, fusion between leaves, and the tubular condition of the first leaf are shown. 15x. (Legend: PE, pericarp; EN, endosperm; EM, embryo; ST, stem; CO, coleoptile; scutellum; SL, strap leaf; AB, accessory blade; L_1 , L_2 , L_3 , first, second, and third foliage leaves, respectively.)

following abnormalities occur singly or in random combinations, and in varying degrees.

(1) A supernumerary "strap" leaf develops at the base of the dorsal side of the first seminal leaf.

(2) Accessory laminae develop on the edges or on the ventral surface of the first two seminal leaves.

(3) The first two seminal leaves are adnate with each other and with the coleoptile, and the sheath of the first leaf becomes greatly extended vertically.

(4) Two successive leaves arise on the same side of the axis.

(5) The apical meristem of the plumule becomes aborted after the formation of one or more seminal leaves.

(6) The distal edge of the coleoptile develops a vasculated, green, leaf-like lamina.

(7) The anterior edges of the scutellum cease to grow and the scutellum fails to enclose the axis.

Abnormality is inherited as a recessive. The symbols Ab, ab, are proposed, referring to "accessory blade."

LITERATURE CITED

1. BRYAN, A. A., AND J. E. SASS
1941. Heritable characters in maize; "Knotted Leaf." Jour. Hered. 32:343-46.
2. EMERSON, R. A., G. W. BEADLE, AND A. C. FRASER
1935. A summary of linkage studies in maize. Cornell Univ. Agr. Exp. Sta. Memoir 180:1-83.
3. KVAKAN, PAUL
1925. Heritable characters in maize. XXIV. Twisted seedlings. Jour. Hered. 16:427-30.
4. SASS, J. E.
1945. Schedules for sectioning maize kernels in paraffin. Stain Tech. 21:93-98.

LIFE HISTORY OF THE WHITE BASS IN STORM LAKE, IOWA¹

WILLIAM F. SIGLER²

*From the Entomology and Economic Zoology Section
Iowa Agricultural Experiment Station*

Received June 18, 1949

The white bass (*Lepibema chrysops*) is one of three important game fish in Storm Lake, Iowa. The others are the yellow pikeperch (*Stizostedion v. vitreum*) and the southern channel catfish (*Ictalurus lacustris punctatus*). The abundant pan fish are black crappie (*Pomoxis nigromaculatus*), northern black bullhead (*Ameiurus m. melas*), and yellow perch (*Perca flavescens*). In addition to game and pan fish, Storm Lake supports a large population of non-game food fish. The forage fish, particularly native minnows, are scarce.

Although the white bass of nearby Spirit Lake has been studied intensively (Sigler, 1949)³, no previous work exists on Storm Lake white bass. Because of the need for life history information, 108 white bass were collected from Storm Lake in the fall of 1942.

Apparently the lake suffered a nearly complete kill in the 1935-1936 winter. Estimates of the fish kill, by personnel of the Iowa Conservation Commission, ranged from 300 to 500 pounds per acre. The dead fish were primarily freshwater drum (*Aplodinotus grunniens*), which were listed as game fish at that time, carp (*Cyprinus carpio*), and buffalo (*Ictiobus* sp. and *Megastomatobus cyprinella*). Between 1910 and 1930 large numbers of carp and buffalo were removed by seining operations of the Iowa Conservation Commission. In 1941 and 1942 the fish taken by seining, according to O. J. Koch of the Iowa Conservation Commission, were mainly buffalo less than three pounds in weight. The few game fish taken (4- and 5-inch, stretched measure, seines) were large pikeperch and large white bass.

Storm Lake is a shallow, eutrophic, natural lake covering an area of 3,060 acres. The depths reported for 1916 by the Iowa State Highway Commission (1917) are a nearly uniform eight feet. According to Glenn Powers of the Iowa Conservation Commission, siltation has reduced the depth of the lake by about one foot up to the present time. In 1939, 1940, 1941, and 1947, the Iowa Conservation Commission dredged about 3,000,000 cubic yards of silt from the east end of Storm Lake. A strip

¹ Journal Paper No. J.-1652 of the Iowa Agricultural Experiment Station, Ames, Iowa, Project No. 764, and the Industrial Science Research Institute, Project No. 45, of Iowa State College; in cooperation with the Iowa State Conservation Commission and the U. S. Fish and Wildlife Service.

² Now Assistant Professor, Department of Wildlife Management, Utah State Agricultural College, Logan, Utah.

³ All references to Spirit Lake are from this paper.

along the east side of the lake was filled in, thus reducing the surface area slightly.

Storm Lake has an abundant summer growth of blue-green algae, but it has no extensive beds of either submergent or emergent plants. According to E. T. Rose of the Iowa Conservation Commission, the city of Storm Lake has spent as much as \$15,000 per year treating the lake with copper sulfate. This practice was discontinued several years ago.

Continuous moderate to high winds during the summer months cause the lake to have a high silt turbidity. The shallow areas of the bottom are largely sand and rock, but the deeper sections of the lake have a silt bottom.

A water analysis of Storm Lake, taken August 21, 1934, was made available through the courtesy of P. J. Hauser, Director, Division of Public Health Engineering, Des Moines, Iowa. According to Hauser, this analysis is probably typical of water at the present time, since there have been no changes except a sewage diversion project whereby treated sewage from the city of Storm Lake is no longer discharged into the lake. Calculated in parts per million by weight, the results of the water analysis are as follows: total solids, 323; methol orange alkalinity, 200; total positive ions, 93.7; total negative ions, 269.1; calcium carbonate hardness, 205. The equivalents per million are as follows: positive ions, 5.395; negative ions, 5.317. The pH is 8.6. These characteristics of the water indicate a typical hard-water lake.

MATERIALS AND METHODS

The age of the Storm Lake white bass was determined by counting the number of scale annuli. Although the validity of this method of aging white bass is not established for the Storm Lake fish, it was proved for Spirit Lake white bass and is believed to be reliable for this study.

The growth rates were calculated with the aid of a nomograph similar to that described by Carlander and Smith (1944). Due to the limited number of specimens and the lack of fish in the shorter length classes, the body-scale relationship of the Storm Lake white bass is assumed to be the same as that of the Spirit Lake white bass; i.e., a straight line relationship with an intercept on the standard length axis of 23.9 millimeters and a slope of 1.88. Van Oosten (1942) lists the Lake Erie white bass as having a straight line body-scale relationship with an intercept of 24 and a slope of 1.08.

All data were taken after the fish had been preserved in 10 per cent formalin for thirty days. Sigler (1949) states that white bass decrease in length and add weight when preserved in formalin. Corrections were, therefore, made by multiplying the lengths by 1.012 and the weight by 0.947.

All collections were made with either a four- or five-inch stretched measure seine. Since the most abundant age group taken consisted of fish in the second year of life, it appears that the young fish are the

only age group excluded by the gear. Advanced age groups could easily have been missed if the number of fish in them was small.

AGE AND GROWTH

The increments of growth, for the first two years of life, were considerably greater for the white bass from Storm Lake than for those from Spirit Lake, but were somewhat less in the third and fourth years of life. The 1939 year-class (III) grew faster than the other year-classes for the first two years of life, but not in the third year (Table 1). There was no definite evidence of a dominant year-class; however the total number taken may be too small to indicate such a trend. In Spirit Lake,

TABLE 1
AVERAGE STANDARD LENGTHS FOR EACH YEAR OF LIFE OF 100 STORM LAKE WHITE BASS
COLLECTED BETWEEN SEPTEMBER 23 AND NOVEMBER 5, 1942

Age Group ¹	Number of Fish	Calculated Length (mm.) at End of Year of Life			
		1	2	3	4
I.	68	108	222		
II.	26	111	223	274	
III.	6	122	246	291	305
Grand Averages and Total.	100	110	224	277	305
Increments of Growth.		110	114	50	14
Equivalent Total Length in Inches ²		5.6	11.4	14.1	15.5
Number of Fish.		100	100	32	6

¹ It is assumed that growth for the current season has been completed. The last lengths given are the lengths at capture.

² The conversion factor from Spirit Lake is used here—standard length (mm.) \times 0.0508 = total length (inches).

the 1941 year-class (age group I here) dominated the white bass population from 1942 through 1946.

The condition factor (*K*) of the white bass from Storm Lake did not increase with age or length (Table 2). Spirit Lake white bass increased in plumpness as the length increased regardless of age. The shorter length classes of Storm Lake white bass were heavier than comparable lengths from Spirit Lake, but the larger Spirit Lake white bass were relatively heavier than the Storm Lake fish. The white bass from Storm Lake did not gain as rapidly in either weight or length in their third or fourth year as did the Spirit Lake fish.

An examination of the gonads indicated that most of the fish would have been mature at the beginning of their third year of life (Table 3). This is in agreement with the findings at Spirit Lake.

TABLE 2
LENGTH-WEIGHT RELATIONSHIP OF 98 STORM LAKE WHITE BASS, TAKEN BETWEEN
SEPTEMBER 23 AND NOVEMBER 5, 1942.

Average Standard Length mm.	Equivalent Total Length in Inches	Average Weight in Ounces	Average Weight in Grams	Average K	Number of Fish
181.....	9.2	7.5	215	3.625	1
207.....	10.5	9.1	257	2.911	3
216.....	11.0	10.0	285	2.808	25
225.....	11.4	11.2	315	2.755	26
235.....	11.9	12.5	353	2.724	10
241.....	12.2	12.3	348	2.485	1
259.....	13.2	18.2	517	2.973	3
264.....	13.4	19.8	561	3.042	7
278.....	14.1	22.5	638	2.975	8
284.....	14.4	23.6	668	2.923	9
296.....	15.0	27.0	765	2.950	1
303.....	15.4	28.4	806	2.907	2
319.....	16.2	33.9	959	2.955	1
326.....	16.6	38.7	1,094	3.157	1

FOOD HABITS

The Storm Lake white bass fed on fish, insects, and crayfish (*Cambarus sp.*). Fish amounted to two-thirds of the entire volume of food analyzed and occurred in 40 per cent of the stomachs (Table 4). Yellow perch were the most abundant fish taken. Carp, black crappie, and bluegill (*Lepomis macrochirus*) were fed on about equally. Adult yellow perch and bluegill are believed to have been less abundant than black crappie and black bullhead. The fact that the perch and bluegill were taken rather extensively may account for their not being more abundant in the lake. Yellow pikeperch, the only game fish taken, was identified from one stomach. Mayflies and crayfish were the only important invertebrates. Although Hemiptera (primarily Corixidae) occurred in twenty-seven per cent of the stomachs, they amounted to only one per cent of the volume. Sigler (1949) reported the fish diet of the Spirit Lake, Iowa, white bass as primarily the young of pan fish. The Spirit Lake white bass fed heavily on the smaller crustaceans, but

TABLE 3
SEX RATIO AND AGE AT MATURITY OF 100 STORM LAKE WHITE BASS COLLECTED IN 1942.

Age Group	Number of Fish	Standard Length (mm.)	Percentage in Each Sex		Percentage Mature	
			Male	Female	Immature	Mature
I.....	68	222	41.2	58.8	72.1	27.9
II.....	26	274	46.2	53.8	3.8	96.2
III.....	6	305	33.3	66.7	.0	100.0
Total.....	100	.....	42.0	58.0	50.0	50.0

only slightly on crayfish. This study indicates the Storm Lake white bass did not feed on the smaller crustaceans in 1942. Bailey and Harrison (1945) reported that the white bass of Clear Lake, Iowa, preferred small fish. However, as opposed to the Storm Lake and Spirit Lake white bass, the Clear Lake white bass fed on black bullheads.

As the season progressed, fish and crayfish decreased in the diet, and insects were taken more frequently. This probably indicates a decrease of available fish rather than an increased preference for insects. Young carp were not taken until November. Sigler (1949) believed that the young carp in Spirit Lake frequented, until late fall, the weedy

TABLE 4

FOOD OF THE 1942¹ WHITE BASS FROM STORM LAKE, IOWA, EXPRESSED AS PERCENTAGES OF FREQUENCIES OF OCCURRENCE AND AS PERCENTAGES OF TOTAL VOLUME OF FOOD ORGANISMS.

Month of Collection and Months Combined	September		October		November		Combined	
Number of stomachs taken.....	57		21		30		108	
Number of stomachs containing food.....	46		11		20		77	
Percentage of stomachs containing food.....	81		52		67		71	
Total volume of food (cubic centimeters).....	91.6		41.2		63.6		196.4	
Total length (inches)								
mean.....	11.2		11.3		14.0		12.0	
minimum.....	10.2		9.4		13.1		9.4	
maximum.....	13.8		14.3		16.2		16.2	
	Occ.	Vol.	Occ.	Vol.	Occ.	Vol.	Occ.	Vol.
Fish.....	46	66	18	66	40	66	40	66
Game and pan fish.....	28	54	9	61	20	30	23	48
Sunfish family.....	15	13			10	9	12	9
Black crappie.....	2	9					1	3
Common bluegill.....	4	1					3	1
Perch family.....	13	42	9	61	10	20	11	39
Yellow pikeperch.....					5	9	1	3
Yellow perch.....	13	42	9	61	5	11	10	36
Non-game fish.....	2	1			10	21	4	7
Minnow family.....	2	1			10	21	4	7
Bluntnose minnow.....	2	1					1	tr
Carp.....					10	21	3	7
Insects.....	63	13	27	1	75	29	61	16
Diptera.....	4	tr					3	tr
Hemiptera.....	34	1	27	1	10	tr	27	1
Ephemeroptera.....	54	12			75	29	52	15
Crustaceans.....	43	20	55	34	15	3	30	17
Crayfish.....	43	20	55	34	15	3	30	17
Leeches.....	2	1			5	1	3	1
Plant material.....	1	tr					1	tr

¹ Collections were made between September 23 and November 5, 1942.

shallow habitat in which they were spawned. White bass did not eat their own young in either Spirit or Storm Lake.

SUMMARY

1. Storm Lake has a large population of non-game fish along with the game and pan fish. Small forage fish, particularly native minnows, are notably lacking. The lake suffered a serious kill in 1935-1936.
2. The age, growth, and food habits of 108 white bass from Storm Lake were studied.
3. Age classes I, II, and III were represented, but young fish were excluded by the gear used.
4. The Storm Lake white bass grew faster than Spirit Lake white bass the first two years but slower thereafter.
5. The condition factor of the Storm Lake fish did not vary markedly with length or age.
6. The diet is composed primarily of pan fish, carp, crayfish, and mayflies.

ACKNOWLEDGEMENTS

Assistance in collecting was received from O. J. Koch and several other members of the Iowa Conservation Commission. Information was supplied by O. J. Koch, Glenn Powers, Tom Moen, and E. T. Rose, all of the Iowa Conservation Commission. Aid in mounting scales and summarizing material was given by Chester Hart, DeMont Walker, and Leslie Arnberger, students at Utah State Agricultural College. Suggestions in the preparation of the paper were given by Dr. K. D. Carlander, Department of Zoology and Entomology, Iowa State College. Sincere appreciation is expressed to everyone concerned.

LITERATURE CITED

- BAILEY, REEVE M. AND HARRY M. HARRISON, JR.
1945. The fishes of Clear Lake, Iowa. Iowa State College Jour. Sci. 20:1:57-77.
- CARLANDER, KENNETH D. AND LLOYD L. SMITH, JR.
1944. Some uses of nomographs in fish growth studies. Copeia. 3:157-62.
- IOWA STATE HIGHWAY COMMISSION
1917. Iowa lakes and lake beds. State of Iowa, Des Moines, Iowa.
- SIGLER, WILLIAM F.
1949. The life history of the white bass in Spirit Lake, Iowa. Iowa State College Res. Bull. in press.
- VAN OOSTEN, JOHN
1942. The age and growth of the Lake Erie white bass, *Lepibema chrysops* (Rafinesque). Papers of Mich. Acad. Sci. Arts, and Letters 27:307-34.

THE WARMOUTH, *CHAENOBRYTTUS CORONARIUS* (BARTRAM), IN RED HAW HILL RESERVOIR, IOWA¹

WILLIAM M. LEWIS AND THOMAS S. ENGLISH

Department of Zoology and Entomology, Iowa State College

Received June 18, 1949

Red Haw Hill Lake is an 80-acre, artificial impoundment located in south central Iowa, near Chariton. The lake was constructed in 1935 and is used exclusively for recreational purposes. Red Haw, along with the neighboring East Lake, supports most of the fishing pressure within a radius of 35 miles.

The majority of the Red Haw watershed is well protected from erosion. The shoreline is very irregular, reducing wind action and resulting in a shallow epilimnion. The maximum depth of the lake is slightly more than 30 feet. Approximately 90 per cent is deeper than 7.5 feet, which is the maximum depth at which higher aquatic plants grow in the lake.

Plankton growth is abundant in the lake, and in late summer, surface algal blooms occur frequently. During much of midsummer and late summer, the algal growth is sufficient to interfere with fishing.

The following species of fish are well represented in the lake: largemouth black bass, *Micropterus salmoides* (Lacépède); bluegill, *Lepomis macrochirus* (Raf.); black crappie, *Pomoxis nigro-maculatus* (LeSueur); white crappie, *Pomoxis annularis* (Raf.); yellow perch, *Perca flavescens* (Mitchill); and warmouth, *Chaenobryttus coronarius* (Bartram).

Although fairly abundant in the lake, warmouth (Fig. 1) are seldom taken by fishermen. In 6,513 man hours of fishing only four warmouth were taken. During the summer months, warmouth frequent the shallow water among the weeds along the bank, where angling is difficult.

The following methods of collecting specimens were used: basket traps, fyke nets, experimental gill nets, seining, and angling.

The majority of the warmouth, fifty-one, were taken in the basket traps. Angling accounted for six, fyke nets for five, and eighteen specimens were captured in gill nets. The basket traps effectively sampled all sizes of warmouth. Gill nets and fyke nets took good samples of the larger individuals. Seining was done with a four-foot minnow seine for young-of-the-year fish. No warmouths of any size were taken by this

¹ Iowa Cooperative Fishery Research Unit Project No. 42, sponsored by the Industrial Science Research Institute of Iowa State College and the Iowa State Conservation Commission, with the cooperation of the U. S. Fish and Wildlife Service.

method, although young-of-the-year of other species were readily collected in this manner.

AGE AND GROWTH

Three scales for the age and growth study were taken from each fish from an area located by compressing the left pectoral fin and placing its tip on the third row of scales below the lateral line. The scales were prepared for projection by mounting them between two glass slides and securing the ends of the slides with adhesive tape. Slides were then placed in water in such a manner that water was drawn up around



FIG. 1.—Warmouth from Red Haw Hill Lake.

the scales by capillary action, and after a short soaking period the scales were read with a microprojector. The annuli were quite distinct on most scales. The relative positions of each scale's focus, annuli, and edge were marked on a strip of paper tag. The growth rates were then calculated from these tag strips on a nomograph.

In this study, standard length was measured from the tip of the snout to the end of the hypural plate. Total length was measured from the tip of the snout to the tip of the tail, the lobes of the tail being compressed. Fork length was measured from the tip of the snout to the fork of the tail. The length conversion factor between standard and fork length is 1.179 and between standard and total length is 1.248. The former is based on sixty-five specimens and the latter on seventy-two specimens in the length range 40 to 177 millimeters. Standard length was used for all calculations in this study unless stated otherwise.

The body-scale relationship of fifty-five warmouths from Red Haw was determined by plotting the mean body lengths at 10 millimeter

intervals against the mean scale radii and fitting a straight line to the data. A line having a slope of 0.77459 and an intercept on the length axis of 13 millimeters appears to define accurately the body-scale rela-

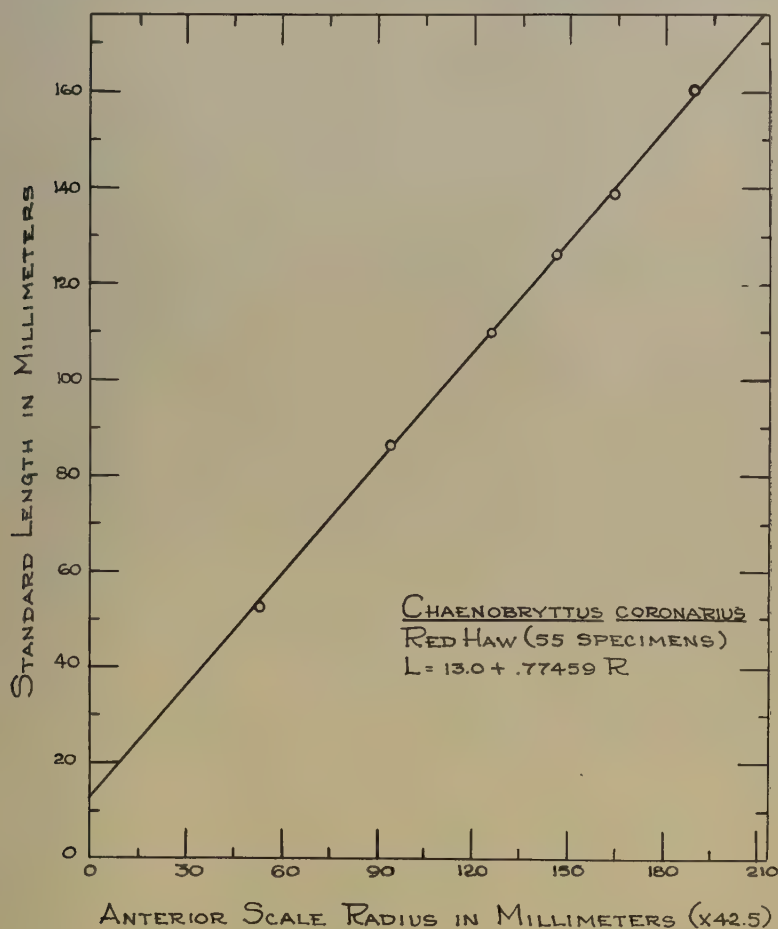


FIG. 2.—Body-scale relationship of warmouths from Red Haw Hill Lake.

tionship (Fig. 2). The growth calculations were made on a direct proportion basis using 13 millimeters as a base.

Since separate calculations of the growth rates failed to indicate any sexual difference in growth, the data for both sexes are combined (Table 1). The annual increase in length was greatest during the first four years of life. The annual increment is less each year after the

TABLE 1
CALCULATED AND MEASURED LENGTHS OF 55 WARMOUTHS FROM RED HAW LAKE.
SEXES COMBINED.

Age Class	Number Specimens	Average Calculated Length at Each Annulus in mm.							Length at Capture
		1	2	3	4	5	6	7	
I.....	5	33	.....	.....	.....	.....	.....	.....	59
II.....	17	32	82	.....	.....	.....	.....	.....	106
III.....	23	31	70	121	.....	.....	.....	.....	133
IV.....	3	32	59	120	155	.....	.....	.....	155
V.....	2	32	67	112	140	159	.....	.....	159
VI.....	4	35	70	105	131	147	160	.....	160
VII.....	1	34	76	117	149	164	170	177	177
Mean standard length mm....		32	73	118	142	153	162	177	.....
Standard deviation of lengths.....		4.6	13.7	14.2	12.5	9.8	8.3	.....	.....
Equivalent total length in inches.....		1.6	3.6	5.8	7.0	7.5	8.0	8.7	.....
Annual increment.....		32	41	49	30	17	12	7	.....
Annual increment in grams..		1	14	53	61	46	39	28	.....

fourth. The annual increment in weight (estimated from the length-weight relationship given later) increases through the fourth year and even in the seventh year is more than the first two years combined. The Red Haw warmouth appear to have grown at a similar or slightly slower rate than warmouth from Indiana and Tennessee (Table 2).

Specimens from seven year-classes are represented in the study. No young-of-the-year were obtained. It is believed that these specimens satisfactorily indicate the year-class abundance except for the 1947 and 1948 classes which may have been more abundant than the sample would indicate. The 1945 and 1946 classes are the best represented among the fish two or more years of age.

Data on the sexual condition of sixty-five warmouth indicates that the earliest spawning occurred during the last week of June. Spawning

TABLE 2
COMPARISON OF TOTAL LENGTHS IN INCHES AT CAPTURE OF II, III, AND IV YEAR
WARMOUTHS FROM INDIANA, TENNESSEE, AND RED HAW LAKE.
Number of specimens indicated in parentheses.

	II	III	IV
Iowa, Red Haw Lake.....	5.2 (17)	6.5 (23)	7.6 (3)
Indiana, Muskellunge Lake (Ricker, 1945).....	5.5 (10)	6.8 (10)	7.2 (25)
Tennessee, Reelfoot Lake (Schoffman, 1940).....	6.2 (44)	7.0 (254)	7.7 (130)

was apparently not completed until the latter part of July, as ripe individuals appeared until that time.

The length-weight relationship of seventy-six Red Haw warmouth (Table 3), covering a length range of 40 to 177 millimeters, may be described by the following formula:

$$\text{Log } W = -4.683 + 3.138 \text{ Log } L$$

where W = weight in grams
and L = standard length in millimeters

The average K value for seventy-six specimens, in the length range 40 to 177 millimeters, is 3.95. There was no detectable change in K with length or sex.

FOOD AND PARASITES

Warmouth appear to be quite predacious in their feeding. The stomach contents of twenty-nine warmouths ranging in length from 40

TABLE 3
OBSERVED AND ESTIMATED WEIGHTS OF WARMOUTHS FROM RED HAW LAKE.

Standard, ¹ Length, mm.	Number of Fish	Weight in Grams		Total Length, Inches	Observed Weight, Ounces
		Observed	Estimated ¹		
45.....	1	4	3	2.2	0.14
51.....	2	4	5	2.5	0.14
67.....	1	10	11	3.3	0.35
76.....	2	16	17	3.7	0.56
83.....	2	22	22	4.1	0.78
93.....	3	31	31	4.6	1.10
105.....	7	48	46	5.2	1.17
113.....	8	57	58	5.6	2.00
126.....	16	79	81	6.2	2.80
135.....	9	101	101	6.6	3.60
144.....	8	120	124	7.1	4.20
154.....	11	143	152	7.6	5.00
163.....	6	172	177	8.0	6.10
177.....	1	264	235	8.7	9.30

$$^1 \text{Log } W = -4.683 + 3.138 \text{ Log } L$$

to 177 millimeters and collected from April through July were examined. Twelve of the stomachs were empty. In the remaining seventeen stomachs, food items occurred as follows: 2- to 4-inch fish, 7; crayfish, 4; vegetable debris, 2; unidentified insect larvae, 4; leech, 1; dragon-fly naiad, 1; unidentified insects, 2; and snails, 1. On a volumetric basis, fish and crayfish were the most important items.

Parasitological examinations were made on sixty-six warmouth ranging in length from 50 to 169 millimeters. The collections were made from the first of April through the first week of September.

Every specimen examined had infestations of *Posthodiplostomum minimum* in at least one organ, but more often in two or more organs.

The metacercariae of this parasite encased the heart of 56 specimens and occurred in the liver of 42, the kidneys of 14, the mesenteries of 6 and the spleen of 1. The degree of parasitism was extremely high. The heart was almost invariably completely encased and the liver and kidney contained uncountable numbers.

Parasitic copepods occurred on the gills of 17 of the 66 specimens. The observed number of these organisms varied from 2 to 30 or more per fish, but frequently there were only 2 or 3 on a specimen.

Leeches were attached to the fins of 9 fish and to the palate of 1. The number of leeches varied from 2 to 5.

The mesenteries of 6 fish were parasitized by 1 to 3 nematodes.

Over 100 black grubs, larval strigeids, were observed scattered through the body muscles of one fish.

Plerocercoids of *Proteocephalus ambloplitis* occurred on the liver of 2 fish and in the ovaries of 3. There were 2 and 3 organisms on the livers and 7 or 8 in each ovary.

Two of the sixty-six specimens had regenerated caudal fins. It is thought that these fish were recovering from *Saprolegnia* infection.

MANAGEMENT

Since the warmouth does not contribute materially to the angler's catch, perhaps the greatest contribution made by the species is as a predator. It rivals the largemouth as a predator capable of controlling the abundance of young bluegills and similar fish. Although practically no work has been done with the warmouth, it may eventually prove to be a predator suitable for use with bullheads or possibly as a predator to supplement the largemouth black bass.

LITERATURE CITED

- RICKER, WILLIAM E.
1945. Abundance, exploitation and mortality of the fishes in two lakes.
Invest. Indiana Lakes and Streams 2(17):345-448.
- SCHOFFMAN, ROBERT J.
1940. Age and growth of the black and white crappie, the warmouth bass, and the yellow bass in Reelfoot Lake. Report Reelfoot Lake Biol. Sta. 4:22-42.

INFLUENCE OF NORMAL AND IMMUNE DUCK PLASMAS ON CHICK INFECTIONS OF *PLASMODIUM LOPHURAE* INDUCED WITH PARASITES IN DUCK ERYTHROCYTES¹

ELERY R. BECKER, CHARLES E. BRODINE, ALICE A. MAROUSEK, AND DORWIN A. BYRD

Department of Zoology and Entomology

Received June 28, 1949

It is now generally accepted by malariologists that the immune state following parasitemia, during which malarial parasites are either not microscopically demonstrable in the circulating blood or are detectable only after prolonged search, is a premunition, or an immunity that is dependent upon the more or less constant stimulation of the defense mechanism of the host by an uneradicated residue of parasites. Such an immune state is characterized by refractoriness of the host to reinoculation with the homologous strain of malarial organism, the appearance in the circulating blood of antibodies that can be demonstrated if suitable tests are made at the proper time, and the ability of the blood of the latently infected host to produce acute infections in normal animals by subinoculation. These statements hold whether or not exo-erythrocytic forms occur in the host. More detailed discussions of these topics are to be found in papers by Coggeshall (3), Maier and Coggeshall (9), and Taliaferro and Taliaferro (11).

The work of the Taliaferros became the starting point for our investigation, because it demonstrated that the course of blood-induced *Plasmodium lophurae* infection in chicks was markedly affected by daily administrations of homologous immune serum from latently infected, and superinfected chickens. The observed depression of the number curves (representing intensity of parasitemia at daily intervals) for the recipients of daily injections of immune chicken serum below the expected levels suggested by the number curves for the recipients of normal chick serum, or of saline solution, or of no injection was ascribed to passively acquired immunity partially protecting the host against the development of the normal infection.

The original purpose was to repeat the Taliaferros' work as nearly as possible using ducklings throughout instead of chicks. However, after repeated failure to alter significantly the course of the infection in ducklings with immune duck plasma in daily dosages of 0.2-2.0 cc.,

¹ This investigation was supported (in part) by Research Grant 605 (C) from the Division of Research Grants and Fellowships of the National Institute of Health, United States Public Health Service.

To Professor G. W. Snedecor, gratitude is expressed for his advice on statistical testing of the data, but he is in no wise responsible for the conclusions that were reached.

it was decided to make the tests in chicks, employing infected duck cells for inoculating and immune duck plasma for treating the infections thus induced. Normal, immune, passage, and relapse duck plasmas and immune chick plasma have been tested in the experiments to be reported.

MATERIALS AND METHODS

The microorganism, *Plasmodium lophurae*, was maintained by blood-passaging through ducklings as previously described (1). It is still assumed that exo-erythrocytic stages do not occur in blood-induced infections of this species. The chicks employed as hosts in the tests were New Hampshires delivered to us from the hatchery when one day old. The ration was a commercial chick starter which has been found satisfactory for health and growth.

Blood for obtaining plasma was drawn from the jugular vein of the duck and transferred to screw-cap test tubes containing sufficient dried anticoagulant to prevent clotting. The anticoagulant was generally heparin, though sodium citrate was used in one or two cases. It has been positively determined that heparin does not affect the sparing action of duck plasma, discussed below. Since further investigation of the effect of heparin is in progress, the results will not be included at this time.

The plasma was drawn off the erythrocytes after centrifugation, transferred to screw-cap test tubes, and kept in the refrigerator. It was made a practice to draw the plasma the day before the test chicks were inoculated with the parasite. Sterile technique was maintained throughout the process of collecting, separating, and storing the plasma.

Blood, as a source of parasitized cells, was drawn from a duck with 70-80 per cent of its erythrocytes parasitized on the fourth or fifth day of the infection. After mixing with the anticoagulant, about 5.0 cc. of blood in a screw-cap test tube was whirled at about 2,000 r.p.m. for five minutes in the centrifuge, then the supernatant plasma was removed. About 12 cc. of physiological salt solution was added to the cell residue and the mixture was shaken to resuspend the red blood cells. After a second centrifugation the red blood cells were resuspended in the amount of physiological salt solution that gave the desired concentration. The computation for obtaining this concentration was based on parasite counts on stained, dried blood smears and total erythrocyte counts made just before the blood was drawn.

Plasma and parasitized erythrocytes were injected into the wing veins. Parasite dosages are expressed in terms of 10^8 per 100 g. of the chick's body weight, and plasma dosage as cc. per 100 g. of the chick's body weight. Details concerning the time and amount of plasma injections, numbers of parasitized cells injected, and the age of the chicks are included in the tables. The histories of the plasma donors and other details appear in the separate accounts of the various series.

The criterion of the effects of plasma administration was the per-

centage of parasitized cells in control and injected groups at appropriate intervals of time. The cell counts were made on dried blood smears stained in Giemsa. The number of cells counted was large enough to give a parasite-erythrocyte ratio with a probable error of 10 per cent (8).

The results appear in Table 1. Only the group means and standard deviations appear in most instances. The formula employed for standard deviation was the square root of the sum of the squared variables divided by the number of chicks, minus the mean squared. The abbreviation G is for group, S for series, C for chick, and P. C. for parasitized cells. It is to be understood that normal duck and normal chick plasmas are from healthy birds that have had no malarial infection, and that immune plasmas are from birds that have recovered from the primary attack of *P. lophurae*.

The results were tested for significances by the Fisher (7) small-sample method. The nature of the variables depended on expediency. In certain cases they were percentages of parasitized erythrocytes for a certain day, while in other cases they consisted of the sum of the percentages for the individual birds over a period of days.

The solution of a problem by the Fisher small-sample method is presented here in the belief that it might be of help to other investigators with similar data to be tested for significance. The format was provided by Professor G. W. Snedecor. The parasitized cell percentages for day 1 of G 1 and of G 2, both of Series 13 and appearing in Table 1, constitute the variables of the groups to be compared. The complete procedure follows:

	G 1	G 2
Number of chicks.....	17	17
Degrees of freedom.....	16 (17 - 1)	16 (17 - 1)
Sum of variables.....	35.2	104.1
Mean of variables.....	2.07	6.12
Sum of squares of variables....	113.90	761.51
Sum \times mean.....	72.86	637.09
Sum of squares of dev. from mean.....	41.04	124.42
Pooled (41.04 + 124.42).....	165.46	
Divided by total degrees of free- dom (16 + 16).....	5.17	
Variance of mean difference [5.17 \times (1/17 + 1/17)] ...	0.608	
Std. dev. of the mean difference ($\sqrt{0.608}$).....	0.780	
$t = (6.12 - 2.07) \div 0.780$	5.19	

In Fisher's table of t , P (probability) for 32 degrees of freedom and t of 5.19 are beyond limits of table. The differences are highly significant. It is to be concluded that the treatment produced an effect.

TABLE 1

Records, by series (1-13), of the mean percentages of parasitized cells in stained smears of chick blood made on selected days (minutes or hours, where so indicated) after inoculation. (Group designations are followed by numbers of chicks constituting the groups. $\pm = <0.05$ per cent.)

SERIES 1

(AGE, 14 DAYS; 3×10^7 P. C.)

Time After Inoculation												
No. of Group	No. of Chicks	1 day	2 days	3 days	4 days	5 days	6 days	7 days	8 days	10 days	12 days	16 days
G 1 *	6	2.68 ± 1.32	4.05 ± 1.40	16.50 ± 8.21	53.50 ± 18.87	43.67 ± 18.60	44.33 ± 16.76	16.50 ± 11.01	15.90 ± 11.70	6.25 ± 8.61	9.00 ± 13.54	2.43 ± 5.32
G 2 †	3	6.90 ± 4.10	7.17 ± 3.91	24.00 ± 5.89	51.00 ± 14.23	30.00 ± 6.16	10.67 ± 2.74	1.30 ± 0.08	0.30 ± 0.00	0 ± 0.0	0 ± 0.0	0 ± 0.00
G 3 ‡	3	3.17 ± 1.93	4.57 ± 2.61	13.33 ± 11.77	23.67 ± 15.01	6.37 ± 3.80	1.47 ± 3.44	0.87 ± 1.22	0.87 ± 1.22	0 ± 0.0	0 ± 0.0	0 ± 0.0
G 4 §	3	5.00 ± 1.14	6.63 ± 1.81	22.00 ± 5.02	27.33 ± 14.56	6.77 ± 6.09	0.27 ± 0.28	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00
G 5 ||	3	5.00 ± 1.61	7.60 ± 1.55	28.67 ± 8.20	59.00 ± 6.40	29.00 ± 4.90	17.47 ± 8.19	2.93 ± 1.64	3.30 ± 2.06	4.27 ± 3.48	3.70 ± 5.16	0 ± 0.00
G 6 ++	4	5.05 ± 2.00	6.28 ± 3.12	24.25 ± 8.93	70.00 ± 8.22	52.50 ± 11.52	45.75 ± 16.52	16.00 ± 13.93	11.60 ± 13.27	19.79 ± 15.38	31.77 ± 22.87	0.03 ± 0.00
G 7 **	7	0.02 ± 0.01	0 ± 0.02	0.04 ± 0.01	0.22 ± 0.20	0.40 ± 0.11	1.10 ± 0.17	2.43 ± 0.92	0.91 ± 1.11	0.13 ± 0.10	0 ± 0.00	0 ± 0.00

* Controls; no plasma.

† 0.6 cc. immune duck plasma, days 0-5.

‡ 0.6 cc. immune duck plasma, days 0-5.

§ 0.6 cc. immune duck plasma, days 0-5.

|| 0.6 cc. immune duck plasma, days 0-5.

++ 0.6 cc. normal duck plasma, days 0-5.

** 0.6 cc. plasma from immune chicks infected from ducks, days 0-5.

The term "sparing action," which appears subsequently in several places, is applied to the protective influence exerted by the treatments in behalf of the parasitized duck erythrocytes injected into the chick. This term was adopted in preference to "protection" in order to avoid confusion with protection afforded the host by treatment.

RESULTS

Series 1.

The six control chicks of G 1 were not treated. Gs 2-5 each consisted of three chicks which received the plasma of one particular 67-day-old duck which had been inoculated when 12 days old, completed the primary attack 9 to 18 days later, and undergone a post-crisis infection of the intermittent type described by Becker, Brodine, and Clappison (2). Smears made immediately before the bloods were drawn from the four donor ducks showed, respectively, 0.07, 0.2, 0.03, and 0.0 per cent infected red cells. The four chicks of G 6 received the plasma of a normal duck. The ducks, four immune and one normal, were males of the same hatching. The chicks of G 7 were recipients of pooled plasma from seven 45-day-old chickens which had been inoculated with parasitized duck cells when 15 days old and given "booster shots" 12 days before the blood was drawn. The various plasmas were administered daily for 6 days commencing two hours before inoculation.

A test made of the counts of Gs 2-5 for day 1 by analysis of variance (10) showed that the groups were not different. Then, using them as a single group, the twelve variables of Gs 2-5 were compared with the six variables of G 1 for day 1 by the Fisher small-sample method to which reference has already been made. The resulting *P*-value was but slightly higher than 0.05, which has arbitrarily been accepted as significant. When the four recipients of normal plasma in G 6 were compared in like manner with the untreated controls of G 1 there resulted a *P*-value of about 0.08 which, though not generally accepted as significant, means that the *t*-value obtained would be exceeded only one time in 12.5. G 7, recipients of immune plasma from chicks infected and superinfected with parasitized duck erythrocytes, obviously exhibited strong resistance throughout the infection. The inordinately low counts on day 1 and the negative counts on day 2 probably resulted from the presence in the immune chicken plasma of both haemolysin toward duck erythrocytes, and antibody to the protozoon.

The next question was whether the immune duck plasmas afforded the chicks a significant degree of passively acquired protection after day 1, the evidence for which, if any, was to be found in the data for days 5-16. The counts for each chick of G 1 and Gs 2-5 for these twelve days were added, each of the blanks for days 9, 11, 13, 14, and 15 being filled by a figure representing an average of the counts on the nearest day before and the nearest day after the missing item. Then the totals were employed as variables in the previously mentioned Fisher small-sample test. The difference between G 1 and Gs 2-5 proved to

be highly significant. A similar test showed no significant difference between G 1 and G 6, but G 1 and G 7 were significantly different.

Series 2.

The controls of G 1 were untreated. G 2 was the recipient on days 0-3, beginning an hour before inoculation, of 0.8 cc. of plasma from a 6-month-old male duck which had been inoculated when 14 days old and, after the crisis, had experienced the intermittent course of infection. The parasitemia was 0.5 per cent at the time the blood was drawn. The counts were low throughout the infections, probably because the

SERIES 2
(AGE, 15 DAYS; 0.8×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation									
		2 days	3 days	4 days	5 days	6 days	7 days	8 days	9 days	13 days	16 days
G 1*	4	.03 ± .00	0.08 ± .04	0.43 ± .44	0.88 ± .94	4.40 ± 4.46	7.20 ± 7.76	16.15 ± 17.80	30.8 ± 11.6	9.37 ± 12.8	0 ± 0.0
G 2†	4	0 ± .00	0.08 ± .04	0.28 ± .16	0.18 ± .05	1.52 ± .99	2.83 ± 2.47	4.78 ± 2.48	8.25 ± 7.08	8.78 ± 14.0	0.1 ± .17

* Control; no plasma.

† 0.8 cc. immune duck plasma, days 0-3.

inoculation consisted of but 0.8×10^8 P. C. On the second day a few parasites were to be found in each chick of the control group, but none could be located in 10,000 cells examined from each chick of the treated group. When the counts for each chick on days 5-9 were added and the totals employed as variables in the Fisher small-sample method of analysis, a *P*-value of about 0.065 resulted, which means that the *t*-value obtained would be exceeded only one time in fifteen.

Series 3.

The controls of G 1 were untreated. The normal plasma administered to G 2 was from a large 6-month-old male duck. The immune plasma employed in G 3 was taken from a 6-month-old male duck which had been inoculated when 14 days old, survived the primary attack, and afterwards exhibited the intermittent type of post-crisis infection (2). On the day the blood was drawn one P. C. was seen in 10,000 erythrocytes examined. The immune chicken plasma was pooled from three 2-month-old chicks, each of which had been inoculated when 2 weeks old with 4×10^8 P. C. of a duck with 80 per cent of its erythrocytes infected. The plasmas were injected 2.75 hours before the infected duck cells.

The data for this series (Table 1) are among the most striking in their implications of any of the series. The mean of 18.8 per cent P. C. for G 3 on day 2 is more than twice as high as that of 7.5 per cent P. C. for G 1 on the same day, and the difference between the means

SERIES 3
(AGE, 12 DAYS; 5×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation								
		2 days	4 days	5 days	6 days	7 days	8 days	10 days	16 days	23 days
G 1*...	6	7.45 ± 4.41	53.5 ± 13.0	47.7 ± 6.78	39.8 ± 14.8	14.5 ± 8.18	12.3 ± 10.9	16.4 ± 20.3	9.78 ± 13.9	+
G 2†...	6||	9.90 ± 3.01	39.3 ± 12.4	14.9 ± 4.82	4.50 ± 8.24	0.47 ± 0.46	0.13 ± 0.26	+	+	0
G 3‡...	6	18.8 ± 4.48	37.2 ± 5.92	5.60 ± 2.57	0.60 ± 0.40	0.29 ± 0.46	0.10 ± 0.10	0	+	0
G 4§...	4	3.25 ± 1.69	16.5 ± 5.93	5.20 ± 5.20	1.04 ± 1.72	+	+	+	0	0

* Control; no plasma.

† 0.7 cc. normal duck plasma, days 0-5.

‡ 0.7 cc. immune duck plasma, days 0-5.

§ 0.7 cc. immune chicken plasma from chickens infected with a duck's P. C., days 0-5.

|| 1 chick died on day 5.

proved to be highly significant, since P 0.01 was obtained. The mean of neither G 2 nor G 4 on the same day was significantly different from that of the control. When the counts for each bird on days 2, 4, 6, 8, and 10 were added and the totals treated as variables, it was found that G 2, G 3, and G 4 were each significantly different from G 1.

The following conclusions can be drawn:

1. The immune duck plasma exerted an initial (i.e., on day 2) sparing action in behalf of the parasitemia induced with parasitized duck cells.
2. Normal and immune duck plasmas and immune chick plasma conferred on the host partial protection against the primary attack, most notably the immune chicken plasma from chicks inoculated with infected duck erythrocytes.

Series 4.

The fifteen control chicks of G 1 were not treated. Each chick of G 2 received 0.9 cc. of pooled plasma from two 140-day-old normal male ducks on days 0, 1, and 2, beginning two hours before inoculation. Each chick of G 3 was treated similarly except that the plasma was pooled from four normal 69-day-old male ducks. G 4 received the plasma from a 69-day-old female duck that had been inoculated when 13 days of age and after the crisis experienced an infection of the sub-latent type (2). Pooled plasma was administered to the chicks of G 5 from four 60-day-old chickens, which had been inoculated with parasites in chick blood when 10 days of age and had received moderately heavy superinfections 2 weeks before the blood was drawn.

When the difference between the means of G 1 and G 2 on day 2 was subjected to the small-sample test, it was learned that it was barely significant, whereas the difference between the means of G 1 and G 3 was not significant. A *t*-value of 1.75 resulted from the test of G 1 and G 4, which is over the 1.734 required for *P* 0.1 in Fisher's table. The mean of G 5 proved to be significantly different from that of G 1 on day 2.

It is obvious that the normal plasma received by G 2 conferred no protection on the host at any time during the course of the infection,

SERIES 4
(AGE, 13 DAYS; 1×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation						
		2 days	3 days	4 days	6 days	7 days	10 days	15 days
G 1*..	15	1.50 ± .62	6.80 ± 4.24	13.4 ± 6.1	29.7 6.4	13.2 ±13.7	3.86 ± 9.45	0.06 ± .02
G 2†..	10	2.06 ± .60	10.80 ± 2.62	18.9 ± 6.9	34.3 ± 6.7	7.70 ±10.4	4.55 ±14.0	0.63 ±1.89
G 3‡..	10**	1.72 ± .61	8.62 ± 3.34	17.3 ± 6.8	13.8 ±20.7	1.56 ± 2.41	0	0
G 4§..	5	2.28 ± .92	8.92 ± 3.35	14.6 ± 3.1	7.02 ± 6.30	0.36 ± .52	0	0
G 5||..	5	0.78 ± .24	4.90 ± .80	8.80 ± 2.8	8.32 ± 9.78	1.14 ± 1.24	0	0

* Control; no plasma.

† 0.9 cc. normal duck plasma, days 0-2.

‡ 0.9 cc. normal duck plasma, days 0-2.

§ 0.9 cc. immune duck plasma, days 0-2.

|| 0.9 cc. immune chicken plasma from chicks inoculated with parasites in chick blood, days 0-2.

** 1 chick died on day 3.

whereas G 3, after the fifth day, and G 4 and G 5, after the fourth day, were partially protected.

Conclusions: (1) The administration of normal duck serum to chicks exerted a sparing effect on the host's activity against the injected parasitized erythrocytes, at least to the second day, in one group, while in another group it did not do so. Immune duck serum seemed to exhibit a similar effect though the differences were not "statistically significant," probably on account of the small number of chicks in G 4.

(2) Immune chick plasma had the counter effect, because the counts for day 2 were significantly lower in the plasma-recipients.

(3) In one of two groups, normal duck plasma conferred partial protection on the host throughout the general course of the infection after the fifth day.

(4) Immune duck and immune chick plasmas likewise conferred partial protection.

Series 5.

The controls, G 1, were untreated except for an injection of 3×10^8 duck P. C. in 1.0 cc. of physiological salt solution. Each chick of G 2 received the same number of duck P. C. in 1 cc. of a half-and-half mixture of passage duck plasma and physiological salt solution, while G 3 received the same, except that, for a certain reason, the plasma was kept at 41°C. for one and a half hours before the injections were started. The saline and plasma-saline injections without duck cells, were repeated on days 1 and 2. Smears made ten minutes after inocu-

SERIES 5
(AGE, 14 DAYS; 3×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation							
		(10 min.)	1 day	3 days	5 days	6 days	8 days	10 days	11 days
G 1*	5	1.56 ± .40	0.25 ± .21	2.32 ± 1.06	10.7 ± 5.04	49.3 ± 13.6	56.9 ± 12.7	23.2 ± 16.4	10.5 ± 12.1
G 2†	5	1.76 ± .60	2.72 ± 2.41	13.4 ± 9.09	35.8 ± 14.8	52.5 ± 10.7	10.9 ± 10.1	7.30 ± 13.1	11.4 ± 20.1
G 3‡	5	1.78 ± .54	1.19 ± 1.24	8.66 ± 8.70	29.3 ± 23.4	48.9 ± 25.1	20.9 ± 17.9	9.82 ± 13.1	8.96 ± 15.8

* Control; no plasma.

† 0.6 cc. passage duck plasma, days 0-2.

‡ 0.6 cc. warmed passage duck plasma, days 0-2.

lation showed approximately the same concentration of P. C. in the blood of the three groups, but twenty-four hours later the mean of G 2 was eleven times that of G 1, and that of G 3 almost five times. At the end of day 3, the ratios were still high, about six and four, respectively.

But because of the great variation within the groups, it was imperative that the data be submitted to statistical analysis, as heretofore. The test of G 1 and G 2 for day 1 yielded P 0.075, and that for G 1 and G 3 yielded P 0.09. The test of G 1 and G 2 for day 3 resulted in P .065, which means that a t -value higher than that obtained would occur only once in about fifteen trials. After the sixth day there was a noticeable tendency for the counts in G 2 and G 3 to decline more rapidly than those in G 1, but statistically the differences were not particularly significant. The warming was also without significant effect.

Series 6.

No plasma was administered to the controls (G 1). Two hours before inoculation the chicks in G 2 received 0.2 cc. of normal duck

plasma, those in G 3 received 0.5 cc. normal duck plasma, and those in G 4 received 0.5 cc. of the same plasma heated at 51.4°C. for one and one-half hours. The means of the four groups were very close ten minutes and two hours after injection, but after a day the average of the means for G 2, G 3, and G 4 was 1.5, while that for G 1 was only 0.8. The mean of G 3 was comparatively low mostly because of C 13,

SERIES 6
(AGE, 14 DAYS; 4×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation					
		(10 min.)	(2 hrs.)	1 day	3 days	5 days	7 days
G 1 *	5||	2.38 ±0.41	2.12 ±0.75	0.82 ±0.37	4.38 ±1.56	19.00 ±6.70	33.5 ±13.67
G 2 †	5||	2.50 ±0.28	2.68 ±0.50	1.46 ±.70	7.68 ±3.36	32.60 ±7.90	28.75 ±6.71
G 3 ‡	5	2.70 ±0.78	1.70 ±1.09	1.12 ±0.89	6.10 ±4.47	26.00 ±22.87	24.10 ±15.40
G 4 §	5	2.76 ±0.52	2.52 ±0.93	1.90 ±0.99	7.44 ±2.60	36.2 ±11.62	39.20 ±13.96

* Controls; no plasma.

† 0.2 cc. normal duck plasma, day 0.

‡ 0.5 cc. normal duck plasma, day 0.

§ 0.5 cc. heated normal duck plasma, day 0.

|| 1 chick died on day 6.

whose blood was parasite-free on that day. When G 2, G 3, and G 4, on day 1, were tested separately against G 1, no *P* of less than 0.1 was obtained. It should be of some significance, however, that not only on day 1, but also on days 3 and 5, the means for the three groups of plasma recipients were higher than the mean of the nonrecipients. The courses of the infections in the four groups, as recorded in the table, show that the single injection of plasma had no protective effect whatever.

Series 7.

The dual purpose of this experiment was (1) to test the possibility of sodium citrate interfering with phagocytosis of duck P. C. and (2) to obtain more data on the sparing effect of normal duck plasma on the removal of duck P. C. from the circulating blood. The controls, G 1, received 2.0 cc. of physiological salt solution on days 0 and 1, beginning one and one-half hours before inoculation. G 2 received the saline solution made up to 0.4 per cent with sodium citrate. The normal plasma was pooled from one male and one female 90-day-old ducks. In this case the duck P. C. were washed three times before the final dilution. The counts after ten minutes were not significantly different. After

SERIES 7
(Age, 21 Days; 3×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation				
		(10 min.)	(1 hr.)	1 day	3 days	5 days
G 1*	5	0.36 ±0.23	0.05 ±0.01	0.03 ±0.03	0.35 ±0.12	1.09 ± 0.54
G 2†	5	0.09 ±0.09	0.03 ±0.02	0.09 ±0.06	0.37 ±0.14	1.05 ± 0.93
G 3‡	5	0.49 ±0.55	0.45 ±0.49	0.31 ±0.36	2.75 ±3.19	10.22 ±10.34

* Control; 2.0 cc. physiological salt solution, days 0 and 1.

† 2.0 cc. of solution containing 0.9% NaCl and 0.4% sodium citrate, days 0 and 1.

‡ 0.4 cc. normal duck plasma + 1.6 cc. physiological saline solution, days 0 and 1.

one hour and five hours (not appearing in the table) the means of G 1 and G 2 were practically the same, but G 3 almost maintained its initial level all the way through. Tests of the differences between G 1 and G 3 for 1 hour, 5 hours, day 1, and day 3, however, did not show statistical significance, so great was the variation within the groups. It is believed, nevertheless, that the differences are real. It is obvious that sodium citrate did not affect the counts.

Series 8.

The controls, G 1, received 0.5 cc. of physiological salt solution on days 0 and 1, and the test chicks, Gs 2-4, received immune duck plasma on day 0 and day 1, beginning two hours before the inoculation, in the following amounts: G 2, 0.1 cc.; G 3, 0.2 cc.; G 4, 0.5 cc. The duck from which the plasma was obtained was a female with an ovary that was enlarging but not as yet ovulating, as was determined after it was bled to death. It was 120 days of age, had been inoculated when fourteen days old and, after recovery from the acute stage, showed a sub-latent type of infection.

The ten minute and three hour counts were not unlike in the four groups. After a day, however, G 4, which received the largest amount of plasma, showed a mean parasitemia of 2.3 per cent while the other three groups averaged only about 1.3 per cent. The test of G 1 and G 4, however, yielded about P 0.10. When, however, G 2 was united with G 1 and the combined groups tested against G 4, P 0.05 was obtained. Since G 2 received only 0.1 cc. of immune plasma per chick, such a testing procedure did not seem improper. When the recorded daily counts of each chick for days 9 and 12 were tested by the small-sample method it was found that G 4 was significantly different from G 1 on both days. It appears that the protective influence of the immune plasma actually began to be felt on day 7, but the test did not indicate significance.

SERIES 8
(AGE, 20 DAYS; 3×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation								
		(10 min.)	(3 hrs.)	1 day	3 days	5 days	7 days	9 days	12 days	14 days
G 1*.....	5	1.54 ±0.61	1.0 ±0.53	1.30 ±0.95	8.2 ±5.46	29.2 ±21.8	30.6 ±39.5	30.3 ±21.2	5.6 ±9.9	3.9 ±7.6
G 2†.....	5	2.10 ±0.10	1.0 ±0.2	1.10 ±.6	8.0 ±7.4	20.4 ±16.0	22.9 ±15.4	8.5 ±4.8	7.6 ±13.3	9.6 ±19.6
G 3‡.....	5	1.90 ±0.33	1.2 ±0.3	1.64 ±0.82	11.0 ±7.0	22.0 ±17.6	20.0 ±11.6	14.9 ±12.9	12.5 ±22.8	5.7 ±11.4
G 4§.....	5	1.42 ±0.34	1.5 ±0.6	2.3 ±0.6	14.0 ±4.9	25.0 ±16.7	10.8 ±13.3	0.42 ±0.79	0.11 ±0.19	+

* Controls; no plasma.

† 0.1 cc. immune duck plasma, days 0 and 1.

‡ 0.2 cc. immune duck plasma, days 0 and 1.

§ 0.5 cc. immune duck plasma, days 0 and 1.

The test also showed that the smaller amounts of plasma, received by G 2 and G 3, did not confer partial protection.

Series 9.

The controls, G 3, received 0.4 cc. of physiological salt solution on days 0 and 1, beginning two hours before inoculation, while G 1 and G 2 received plasma from a relapsing duck in the same amounts. The male plasma donor, forty-three days old when bled, had been inoculated when thirty days of age and survived the acute attack. By the eighth day of the infection the parasitemia had dropped to 1.2 per cent and

SERIES 9
(AGE, 16 DAYS; 2.5×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation							
		(5 min.)	(1.75 hrs.)	1 day	2 days	3 days	5 days	6 days	8 days
G 1*.....	10	2.31 ±.671	1.64 ±0.728	1.67 ±1.09	5.72 ±2.14	11.58 ±6.35	37.26 ±19.93	45.12 ±16.73	22.41 ±14.6
G 2†.....	10	2.45 ±0.554	1.38 ±0.557	1.73 ±0.91	6.26 ±2.79	10.13 ±5.53	37.70 ±17.12	52.17 ±20.15	27.88 ±22.11
G 3‡.....	10	2.16 ±0.875	1.40 ±0.967	1.00 ±0.88	3.78 ±2.54	7.03 ±6.9	23.46 ±19.44	39.88 ±17.23	30.67 ±11.98

* 0.4 cc. relapsing duck plasma, days 0-2.

† 0.4 cc. adsorbed relapsing duck plasma, days 0-2.

‡ Control; 0.4 cc. physiological salt solution, days 0-2.

by the ninth day to 0.87 per cent. On the twelfth day a parasitemia of 4.7 per cent was noted, and on the next day, when it was bled, it was 42 per cent. The bird died two days later. A smear made of the blood after death showed a parasitemia of over 50 per cent. The "adsorbed plasma" had been mixed with 4×10^8 duck P. C. per cc. and maintained at 37°C. for one and three-fourths hours before it was injected.

The table shows that the mean counts of the three groups for five minutes and one and three-fourths hours were practically the same, and the mean counts for G 1 and G 2 for day 1 were almost identical. Testing of the counts for the twenty plasma recipients (G 1 and G 2) on day 1 against those for the ten controls (G 3) yielded P 0.07. The authors believe the difference is significant, nevertheless, especially in view of the fact that the means of G 1 and G 2 on day 1 were 73 and 70 per cent, respectively, of their five-minute means, while the mean of G 3 for the same day had fallen to 46 per cent of its level at five minutes. The discrepancies are about 59 per cent and 52 per cent, respectively, when 46 per cent is taken as the denominator.

It is obvious that this relapse plasma conferred no degree of protection on the recipients.

Series 10.

There were but two groups in this series: G 1, which received only physiological salt solution, and G 2, which received the plasma of a relapsing duck. The saline and plasma injections were in 0.5 cc. amounts for the first three days, beginning two hours before inoculation, and 1 cc. amounts on the next day. The duck was a large 125-day-old male which had been inoculated when 2 weeks of age, recovered from the acute attack, and thereafter apparently experienced an infection of the intermittent type until it was found relapsing with a 35 per cent parasitemia on the 111th day of the infection. Since it had not been examined for several days previously, it was not known whether the parasitemia was on the increase or decrease, and since the duck was bled to death there was no way of determining this point. The counts after ten minutes, two hours, and six hours appear in the table but do not indicate any significant trend, although the ten-minute counts for the relapse plasma group were higher and the advantage passed to the other group thereafter. On day 1 the controls had 2.5 times as intense parasitemia as the test series, and maintained an advantage throughout. When the counts on each chick for days 1, 2, 3, 4, 5 (equals an average of days 4 and 6), and 6 were added and the totals treated as variables, the difference between the groups was highly significant.

The conclusion is that, since the blood of this relapsing duck was so highly charged with antibody, its effects were already indubitably apparent one day after the first injection into chicks. The host had already passed the crisis of the relapse state.

SERIES 10
(AGE, 15 DAYS; 4×10^8 P. C.)

No. of Group	No. of Chicks	Time After Inoculation									
		(10 min.)	(2 hrs.)	(6 hrs.)	1 day	2 days	3 days	4 days	6 days	9 days	16 days
G 1*	5†	4.9 ±1.1	4.1 ±0.8	2.0 ±0.6	2.2 ±0.2	9.3 ±1.8	14.0 2.2	47.3 ±8.1	66.0 ±5.1	24.0 ±4.0	32.0 ±18.4
G 2†	5	6.8 ±1.5	2.4 ±0.6	1.6 ±0.2	0.9 ±0.1	2.7 ±0.5	3.3 ±0.5	6.4 ±1.0	3.8 ±0.9	5.9 ±8.1	0

* Controls; 0.5 cc. physiological salt solution, days 0-3.

† 0.5 cc. relapsing duck plasma, days 0-2; 1.0 cc., day 3.

‡ 1 chick died on day 8.

Series 11 and 12.

In these series, the sparing effects of duck plasma on the removal of duck P. C. from the circulating blood were not apparent. In Series 11 there were six chicks in each of five groups injected on days 0 and 1, as follows: G 1, controls, recipients of 0.5 cc. physiological salt solution; G 2 and G 3, recipients of 0.5 cc. and 0.2 cc., respectively, of plasma from an immune 150-day-old male duck with a post-crisis infection of the latent type; G 4 and G 5, recipients of 0.5 cc. and 0.2 cc. of plasma, respectively, pooled from two normal 65-day-old male ducks. The plasma was administered in the vein of one wing immediately before the parasitized cells suspended in physiological salt solution were injected into the vein of the other wing. At 1.75 hours after inoculation, the means of the five groups in numerical order were: 2.3, 2.0, 2.0, 2.2, 2.0. After one day: 4.4, 4.8, 2.9, 5.1, 5.5. After three days: 22, 24, 20, 26, 27. After six days: 19, 26, 32, 10, 37. Certainly neither a significant sparing effect nor a notable partial protection could be claimed for any of the plasma injections on the basis of such data.

In Series 12 there were three groups of five chicks each treated as follows: G 1, 0.5 cc. of physiological salt solution on days 0 and 1; G 2, 0.3 cc. of plasma on days 0 and 1 from a male immune duck with a post-crisis course of infection of the sublatent type; G 3, the same as G 2 except that the plasma amounts were 0.5 cc. The mean counts at the end of the following intervals after inoculation were practically identical: one hour, 0.9, 1.1, 1.2; one day, 0.7, 1.0, 1.0; three days, 3.7, 4.5, 4.9; five days, 28.8, 33.0, 34.2; and eight days, 23.0, 17.4, 14.2.

These two series do not appear in the tables.

Series 13.

Since this series is the most impressive of all in demonstrating the sparing effect of duck plasma on duck P. C., the complete record of the parasitemia is permitted to appear in the table. The number of

SERIES 13
(AGE, 12 DAYS; 5.5×10^8 P. C.)

	Chick	Time After Inoculation					
		(5 min.)	1 day	3 days	5 days	7 days	10 days
G 1* (control)	583	5.5	1.5	11	35	33	1.0
	584	5.1	3.7	35	51	12	0.1
	585	5.3	3.2	23	65	31	31.0
	586	2.1	0.3	2	6	10	+
	587	4.9	3.0	36	65	33	24.0
	588	1.0	0.1	1	5	7	0.0
	595	4.7	0.9	10	41	19	0.1
	596	5.5	4.8	20	58	37	59.5
	597	3.5	1.4	12	50	4	0.0
	598	2.7	1.2	12	37	7	+
	599	4.2	4.7	25	64	16	0.3
	600	2.7	0.6	4	16	12	0.0
	607	5.4	1.8	9	53	31	5.8
	608	3.7	0.6	4	19	12	0.0
	609	1.9	0.3	2	14	3	0.0
	610	5.4	3.4	20	54	19	0.0
	611	5.1	3.7	34	68	1	0.0
	Total	68.7	35.2	260	701	287	121.8
	Mean	4.04	2.07	15.3	41.2	16.9	7.2
G 2† (plasma recipients)	589	2.8	8.7	28	41	4.0	0.0
	590	4.5	10.6	37	48	13.0	0.2
	591	5.3	2.8	20	11	0.1	0.0
	592	4.8	8.4	25	21	0.2	0.0
	593	5.0	6.3	38	44	0.2	0.0
	594	3.9	9.3	34	46	10.0	0.2
	601	6.0	10.2	33	55	25.0	1.5
	602	3.0	4.6	23	48	1.5	0.0
	603	5.0	5.9	30	32	2.7	0.0
	604	4.6	2.8	20	37	0.2	0.0
	605	4.1	6.6	30	28	1.4	+
	606	4.7	4.7	26	35	0.3	0.0
	612	4.1	3.4	24	41	13	0.0
	613	2.9	8.2	38	35	1	0.0
	614	4.7	1.1	9	29	3	0.0
	615	4.3	4.9	36	26	0.3	0.0
	616	4.9	5.6	31	22	0	0.0
	Total	74.6	104.1	482	599	75.9	1.9
	Mean	4.39	6.12	28.4	35.2	4.5	0.1

* Controls; 1.0 cc. physiological salt solution on day 0.

† 1.0 cc. immune duck plasma on day 0.

duck P. C. injected was large, *viz.*, 5.5×10^8 P. C. The cells were washed three times in physiological salt solution before the final dilution. G 1 received 1.0 cc. of physiological salt solution one and one-half hours before injection of the P. C., while G 2 received 1.0 cc. of pooled immune duck plasma. The donor ducks were two 60-day-old males which had experienced the latent type infection following the crisis 20 days before the bloods were drawn. There were seventeen chicks in each group, and they were injected in the order of their numerical designations, not in the order in which they appear in the table.

At the five-minute mark the mean counts for the two series were not unlike, but after twenty-four hours the mean of G 2 was practically three times that of G 1, and, it should be noted, the mean of G 2 rose over the twenty-four-hour period, while that of G 1 declined almost 50 per cent. The difference between the means of the two groups is highly significant, according to the Fisher small-sample test. The mean of G 2 was not quite twice that of G 1 by the third day, but here again the difference is highly significant. The controls had more than caught up with the plasma-recipients by the fifth day, and surpassed them in an impressive manner by the seventh day. In fact, the differences on the latter day were statistically highly significant; *i.e.*, the *P*-value was less than 0.01. Evidently, then, the single administration of plasma contained sufficient antibody to confer, passively, a degree of protection.

SUMMARY AND DISCUSSION

The present discussion will be brief and will be limited mostly to what has actually been proved and to pointing out what may be the significance of these results. First, it has been proved that immune and normal duck plasma very often exert a sparing action on the removal of parasitized duck erythrocytes from the peripheral circulation. The potency of this action was in some cases practically nil (Series 3, 11, 12), in others it was apparently slight (Series 1, 4, 6, 7), in others again it was more or less significantly strong (Series 1, 4, 5, 8), while in certain cases it was exceedingly strong (Series 3, 13). While the most striking results were obtained with plasma from immune ducks with various types of post-crisis infections, the sparing effect was also produced with the plasma of normal ducks. Passage plasma also seemed to exhibit a similar sparing action (Series 5).

Secondly, it has been proved that immune duck plasma, when administered in sufficient amounts and with sufficient frequency, may confer a passively acquired protective effect on chicks inoculated with parasitized duck cells. The differences obtained may be statistically significant or near-significant (Series 1, 2, 3, 4, 8, 10, 13). The potency of the immune duck plasma used in this way does not compare unfavorably with that of immune chicken serum administered to chicks, as reported by Taliaferro and Taliaferro (11). Normal duck plasma may also at times exert demonstrable partial protection when administered to chicks which are later injected with infected duck cells (Series 3, 4).

Thirdly, immune chicken plasma from chicks originally inoculated with parasitized duck cells has been shown to possess extremely strong protective powers when injected into chicks inoculated with parasitized duck cells (Series 1, 3). The extreme potency of such plasma is probably due to a combination of haemolysin and antibody to the malarial parasite, but immune plasma from chicks originally inoculated with parasitized chick cells may also exert a notable partially protective action (Series 4).

The sparing action of duck plasmas on the removal of duck cells, parasitized with *P. lophurae*, from the circulating blood of the chick may possibly be of significance, not only as a partial explanation of relapse in *lophurae*-malaria, but also of the physiological problem of why the macrophages of certain organs of the body, such as the spleen, do not normally phagocytose normal erythrocytes while removing misshapen, effete, or diseased erythrocytes from the circulation.

What are the possibilities of the part played by the aforementioned sparing action in the mechanism of relapse in malaria? In a number of series (*viz.*, 1, 3, 4, 8, 13), immune plasma revealed an initial sparing action, but after continued administration proceeded to confer a degree of protection on the host. In certain series (2, 10), the protective effect was apparent so early that the sparing effect, if any, was obscured. If one were to conceive of the sparing effect as evidence of the operation of a fundamentally basic sparing mechanism toward preserving all erythrocytes, except the most abnormal, and of malarial antibody (opsonin) as a substance which excludes parasitized erythrocytes from the protection afforded red cells by normal plasma, then a start would have been made toward formulating a theory of relapse in accord with the observed facts. It is generally accepted theory at the present time that opsonin is more concentrated in the blood immediately after the initial acute attack than it is some time later, and that constant stimulation of the defense mechanism of the host is required to maintain the immune state known as premunition.

Presumably, then, relapses would occur when malarial opsonin concentration becomes very low, as in the relapsing duck of Series 9. If it could be proved that relapse occurs at such time as the sparing potency of the plasma exceeds the potency of the opsonin, as it normally would during the development of the acute attack in the duck before the crisis, then a better understanding of the cause of relapse would have been attained. Furthermore, if it could be shown that the different degrees of efficiency of the sparing action in different ducks are related to the various courses taken during the post-crisis infection (2), then a much better understanding of why certain ducks exhibit the recrudescence type of post-crisis infection, with marked relapses, would also be attained.

The authors have only begun to study relapses with the above-stated hypothesis in mind. Series 9 was concerned with the plasma of a duck taken in relapse and, we believe, demonstrated both that there was no,

or at least very little, antibody concentration in the blood at the time the blood was taken and the plasma exhibited sparing action. The results obtained in Series 10 would seem to indicate that the blood was drawn after the host had reacted powerfully to the increasing parasitemia, and at that moment the blood was powerfully charged with antibody. Thus the ascertaining of how far the relapse was proceeded and to what degree the host has reacted, when a duck is taken in relapse, presents grave, though perhaps not insurmountable, problems.

The criticism will very naturally be made that the phenomenon which we call the sparing action is simply the result of blocking the R-E system. It is held by the authors that the effect observed is not the result of blocking in the ordinarily accepted immunological sense because, as was pointed out above, the first injection of plasma may produce the sparing effect, while continued injections on consecutive days may actually result in partial protection to the host. In the process of blocking, in the ordinarily accepted sense of the term, injections of the blocking material are continued in order to immobilize the bodily defenses.

CONCLUSIONS

1. Immune and normal duck plasmas may exert a sparing action on the removal of duck erythrocytes, parasitized with *Plasmodium lophurae*, from the peripheral circulation of chicks.

2. Plasma from ducks recovered from the primary attack may confer a passively acquired partial protection on chicks inoculated with parasitized duck cells.

3. Plasma from normal ducks may also exert a similar protective effect.

4. Plasma from immune chickens originally injected with parasitized duck erythrocytes exhibits an extremely potent protective action in infections in chicks inoculated with parasitized duck cells.

5. Plasma from immune chicks originally injected with parasitized chicken erythrocytes may also exhibit potent protective properties in chick infections originating from parasitized duck erythrocytes.

6. Plasma taken from ducks in relapse may exert an initial sparing effect on the removal of duck erythrocytes from the blood of injected chicks, or exhibit extremely potent antibody properties almost from the very start. The difference in behavior is, presumably, attributable to whether or not the host has reacted to the recrudescence of the parasitemia.

7. Further study of relapses is indicated.

8. The interrelationships of the aforementioned sparing action of duck plasma and concentration of antibody in duck blood constitute a problem that may have important implications in the problem of the nature of relapse in *lophurae-malaria*.

LITERATURE CITED

1. BECKER, E. R.

1949. Report on thirty-five drugs and three plant materials tested against *Plasmodium lophurae* in the White Pekin duck. Iowa State Coll. Jour. Sci. 23:185-94.

2. ———, C. E. BRODINE, AND B. L. CLAPPISON
1949. Post-crisis in blood-induced *Plasmodium lophurae* infections in White Pekin ducks. *Ibid.* 23:237-47.
3. COGGESHALL, L. T.
1940. The occurrence of malaria antibodies in human serum following induced infection with *Plasmodium knowlesi*. *Jour. Exp. Med.* 72:21-31.
4. ———, AND H. W. KUMM
1937. Demonstration of passive immunity in experimental monkey malaria. *Ibid.* 66:177-90.
5. ——— AND ———
1938. Effect of repeated superinfection upon the potency of immune serum of monkeys harboring chronic infections of *Plasmodium knowlesi*. *Ibid.* 68:17-27.
6. ——— AND M. D. EATON
1938. The quantitative relationship between immune serum and infective dose of parasites as demonstrated by the protection test in monkey malaria. *Ibid.* 68:29-38.
7. FISHER, R. A.
1930. Statistical methods for research workers, p. 109. Oliver and Boyd, Edinburgh.
8. GINGRICH, W.
1932. Immunity to superinfection and cross-immunization in malarial infections in birds. *Jour. Prev. Med.* 6:197-246.
9. MAIER, J. AND L. T. COGGESHALL
1944. The duration of immunity to *Plasmodium knowlesi* malaria in Rhesus monkeys. *Jour. Exp. Med.* 79:401-30.
10. SNEDECOR, G. W.
1934. Calculation and interpretation of analysis of variance and covariance. Iowa State College Press, Ames, Iowa.
11. TALIAFERRO, W. H. AND L. G. TALIAFERRO
1940. Active and passive immunity in chickens against *Plasmodium lophurae*. *Jour. Inf. Dis.* 66:153-65.

GROWTH AND FOOD HABIT STUDIES OF SMALLMOUTH BLACK BASS IN SOME IOWA STREAMS¹

WILLIAM HAROLD TATE²

Department of Zoology and Entomology, Iowa State College

Received July 1, 1949

In the early days most of the streams of northeastern Iowa provided good fishing for smallmouth black bass, *Micropterus dolomieu dolomieu* (Lacépède). Many of these streams still support bass, but in others the bass are gone. The present study was initiated in July, 1947, to secure the scientific information necessary for management of the streams for better bass fishing.

DESCRIPTION OF STREAMS

Coffin (Prairie³) Creek near Manchester, Delaware County, was selected as the chief site for study. It supported a dense population of smallmouth and its small size and clean water provided excellent opportunity for observation. At low water stages in the summer this stream varied in width from ten feet at the narrowest riffles to forty feet in the widest pools. The depth varied from six inches at the wider riffles to a maximum depth of six to eight feet in the deepest pools. Most pools had a maximum depth of three to four feet.

Early in the summer two stations were established along Coffin Creek. One mile of stream west of the bridge near Rocky Hill School (T 89N R 6W Sec. 26) was designated as Station 1, and that section of stream east of the bridge to the point where Coffin Creek enters the Maquoketa River was designated as Station 2. Later in the summer Station 1-A was established as the mile of the creek directly upstream from Station 1. Stations 1 and 2 were similar in respect to bottom type with gravel in riffles and sand or sand silt in the pools. The bottom at

¹Iowa Cooperative Fisheries Research Unit Project 38, sponsored by the Iowa State Conservation Commission and the Industrial Science Research Institute of Iowa State College, with the cooperation of the United States Fish and Wildlife Service.

²The author wishes to express his appreciation to all who have aided in this study: To David Fitzpatrick and G. H. Gill of Manchester, Frank Brecht of Norway, and Earl Scherf of the State Conservation Commission for information on the streams; to Dr. T. G. Scott, Dr. Elmo Hardy, and Dr. William C. Starrett for aid in identification of food items; to Dr. H. M. Harris and Dr. George Hendrickson of the Department of Zoology and Entomology for suggestions; and to Dr. Kenneth D. Carlander for guidance and suggestions.

³This creek is listed on the maps as Prairie Creek but is known locally as Coffin Creek. This more distinctive name is used here³ since Prairie Creek in Benton County was also investigated.

Station 1-A differed from the other two stations. Most riffles had rubble or boulder bottom, and gravel was common at the tail of pools.

Six other Iowa streams were investigated to obtain specimens of smallmouth for comparative data. Four of these streams, Lime Creek near Brandon in Buchanan County, Lamont Creek north of Dundee in Delaware County, Prairie Creek south of Norway in Benton County, and Beaver Creek near Aplington in Butler County, were small streams with the same general characteristics as Coffin Creek; but Prairie Creek and Beaver Creek were characteristically slightly turbid due to suspended silt. Two streams, the Maquoketa and Yellow Rivers, were larger.

AGE AND GROWTH

Scales were collected from 104 smallmouth black bass taken by angling during the summer of 1947. In addition scales from six small bass, seined from the Des Moines River by Dr. William C. Starrett, and from eight specimens from Iowa lakes were studied for comparative purposes. All fish were measured fresh and all lengths are given as standard lengths, unless otherwise mentioned. Length conversion factors based upon 104 specimens were computed as follows:

Fork length = 1.17 standard lengths

Total length = 1.24 standard lengths

Total length = 1.06 fork lengths

The body scale relationship was determined by plotting the mean body lengths at 20 millimeter intervals against the mean scale radii and fitting a straight line to the data by the least squares method (Table 1). The point of interception of this line with the length axis was 44 millimeters, which was used instead of zero as the base for

TABLE 1
BODY-SCALE RELATIONSHIP OF 103 SMALLMOUTH BLACK BASS FROM SEVEN IOWA STREAMS

Standard Length in Millimeters	Number of Fish	Anterior* Scale Radius	Calculated† Scale Radius
103.....	4	31	33
120.....	3	47	42
138.....	4	51	52
159.....	10	64	63
181.....	14	75	74
199.....	30	82	84
221.....	20	89	95
239.....	8	108	105
258.....	4	119	115
273.....	3	118	123
299.....	3	140	137
Total.....	103		

* Expressed as millimeters at a magnification of 27x.

† L = 41 mm. + 1.88R.

growth calculations made on a direct proportion basis with a nomograph (3).

Although only the growth data from four streams can be considered based upon enough specimens to be considered significant, the data on all specimens are recorded in Table 2 for the sake of completeness. The greatest increase in length occurred in the first year and the annual increment in length decreased each year thereafter, but the annual increment in weight (as estimated from the length-weight relationship discussed later) continued to increase as the bass got older.

TABLE 2

AVERAGE CALCULATED LENGTHS AT THE END OF EACH YEAR FOR SMALLMOUTH BLACK BAS FROM EIGHT STREAMS AND THREE LAKES IN IOWA S

Source and Date	Number of Fish	Standard Length in Mm. at Each Annulus							
		1	2	3	4	5	6	7	8
Lamont Creek, 1947.....	8	88	139	202	248	.....	.....	.....	.....
Coffin Creek, 1947.....	67	75	116	170	203	.....	.....	.....	.....
Lime Creek, 1947.....	11	76	121	170	188	.....	.....	.....	.....
Maquoketa River, 1947.....	5	73	116	151	175	.....	.....	.....	.....
Prairie Creek, 1947.....	10	70	109	150	168	218	242	273	.....
Yellow River, 1947.....	1	73	124	181	216	.....	.....	.....	.....
Beaver Creek, 1947.....	1	67	115	152	191	.....	.....	.....	.....
Des Moines River, 1947.....	6	73	.....	.....	.....	.....	.....	.....	.....
West Okoboji Lake, 1941.....	3	77	115	152	178	204	203	226	.....
Spirit Lake, 1941 & 1942.....	2	76	108	142	177	216	251	282	297
Clear Lake, 1941 & 1947.....	2	86	116	159	201	239	287	315	336
Total.....	116	.....	.....	.....	.....	.....	.....	.....	.....
Average.....	.....	76	117	167	189	218	247	275	311
Equivalent total length in inches.....	.....	3.7	5.7	7.8	9.8	11.7	14.0	15.4	16.4
Average increment in millimeters.....	.....	76	42	46	36	34	29	28	32
Average increment in grams.....	.....	12	29	59	82	108	125	151	226

Most of the bass came from four streams (Table 3). The fastest growth was exhibited by the Lamont Creek smallmouth which reached the legal length of ten inches near the end of their third summer of growth. Bass from Coffin Creek attained the ten-inch legal length during their fifth summer of life, and the bass in Lime Creek reached the length of ten inches near the end of their fifth summer. Growth in the first three years was as rapid in Lime Creek as in Coffin Creek but appeared to be retarded during the fourth year. The smallmouth from Prairie Creek were collected in two groups. The members of the first group, taken in August, were all slow growing fish of four years or more of age. The individuals collected in September were young, fast growing fish and were in noticeably better condition when collected. Three smallmouth collected in September were in their fourth summer

of life and all were above the legal size limit of ten inches; while none of the five smallmouth in their fifth summer of life when collected in August was over ten inches in length. This difference may be due to the small size of the samples taken or it may indicate the presence of two populations of bass in this small creek. The absence of fish over four years of age in three small streams suggests the possibility that there may be a movement of smallmouth toward the larger streams.

TABLE 3
AVERAGE CALCULATED LENGTHS OF SMALLMOUTH BLACK BASS IN EACH AGE CLASS, COLLECTED
FROM FOUR SMALL IOWA CREEKS, JULY TO SEPTEMBER, 1947

Age Class	Number Examined	Standard Length in Mm. at Each Annulus							Standard Length at Capture
		1	2	3	4	5	6	7	
A. Coffin Creek									
I.....	9	83							126
II.....	10	68	112						160
III.....	42	76	117	171					210
IV.....	6	75	116	163	203				232
B. Lamont Creek									
I.....	2	85							126
II.....									
III.....	3	88	134	205					264
IV.....	3	90	143	199	248				283
C. Lime Creek									
I.....	1	77							152*
II.....	1	67	113						183*
III.....	6	79	126	176					188
IV.....	3	73	114	154	188				208
D. Prairie Creek									
II.....	1	78	124						185
III.....	3	70	122	186					235
IV.....	5	69	97	130	164				195
VII.....	1	73	113	146	187	218	242	273	305

* Caught in September.

The collection of sixty-seven smallmouth from Coffin Creek included forty-two 3-year-olds (1944 year class). Further investigation is necessary before this year class can be identified as a dominant year class. The fact that this was the youngest age group in which all members were susceptible to angling probably influenced the result. Angling and observation indicated that older or larger fish were very scarce. All angling in this stream occurred within three miles of its mouth. The larger fish may have moved into the Maquoketa River and contributed to the relative dominance of the 1944 year class.

Tester (9) stated that the average female smallmouth black bass from Perch Lake, Ontario, grew at a slightly slower rate than the males but the difference was not detected in later years of life. Bennett (2) was unable to find a consistent growth differential between the

sexes of smallmouth black bass in Wisconsin. The average growth rates of twenty-two female and of sixteen male 3-year bass from Coffin Creek were found to be almost identical and when analyzed statistically (*t* test) the mean differences did not approach significance.

The sex ratio of ninety-five smallmouth black bass taken from two streams was fifty-three males to forty-two females. All of the bass over 8.4 inches, total length, or in their third year of life were mature

TABLE 4
COMPARISON OF SMALLMOUTH BLACK BASS GROWTH IN VARIOUS AREAS

Locality and Authority	Average Total Length in Inches by Age Class							
	1	2	3	4	5	6	7	8
Iowa..... (Present study)	5.6	8.1	10.4	10.7	11.7	.....	14.1	16.5
Norris Reservoir..... (Stroud, 1948)	3.1	8.9	13.3	15.8	17.4	18.1	18.6	.....
Michigan..... (Beckman, 1949)	5.9	9.0	11.2	13.3	15.0	15.3	16.4	16.8
Ontario Lakes..... (Doan, 1940)	6.0*	7.4	9.4	11.8	13.2	13.9	14.6	15.2
Perch Lake, Ontario..... (Tester, 1932)	4.4*	6.6	8.2	9.9	11.1	12.4	13.3	13.8
Wisconsin..... (Bennett, 1938)	2.4†	5.7	8.8	11.4	13.4	14.8	15.9	16.9
Maine Lakes and Ponds..... (Fuller and Cooper, 1946)			7.9	9.9	11.6	13.0	14.6	15.4
Lake St. George, Maine..... (Fuller and Cooper, 1946)			6.3	7.6	9.6	11.5	13.0	14.2

* Converted from standard length using Beckman's (1945) factors for conversion.

† Calculated lengths at end of growing season.

enough to spawn the following spring. Among the thirteen 2-year fish, only two were immature and these were the two smallest in the age class: a female of 5.7 inches and a male of 6.3 inches. None of the 1-year fish was mature although some of the males were 7.5 inches, total length. Maturity is apparently controlled by age and by length. Eschmeyer (5) found that all 2-year smallmouth bass collected from Norris Reservoir were mature.

The growth rate of the smallmouth black bass varies considerably within its natural and introduced range (Table 4). This variation indicates the necessity for growth study in any area where management is contemplated. The most rapid rate of growth was reported by Eschmeyer (5) for the smallmouth introduced into Norris Reservoir, Tennessee. Although the growth rate has decreased since 1940, it is

still greater than in other areas (7). The slowest growth occurs in Ontario Lakes near the northern limit of the smallmouth's range (9) and in Lake St. George, Maine, where the smallmouth was introduced (6). The smallmouth from the Iowa streams apparently grow at a slower rate than those of Michigan (1) and Wisconsin (2). The Wisconsin and Michigan smallmouth were chiefly from lakes which may partly account for the greater average growth rate.

LENGTH-WEIGHT RELATIONSHIP

The relationship between standard length in millimeters (L) and weight in grams (W) from Iowa streams (Table 5) can be described by the following formula:

$$\text{Log } W = -4.8128 + 3.09353 \text{ Log } L$$

The coefficient of condition (K) has been widely used to express the relative plumpness of fish:

$$K = \frac{W 10^5}{L^3}$$

where W = weight in grams
and L = standard length in millimeters

The average K for 104 smallmouth bass collected from Iowa streams in 1947 was 2.49 (Table 5), which indicates that the fish were heavier for their length than has been reported for smallmouths elsewhere.

TABLE 5
THE LENGTH-WEIGHT RELATIONSHIP AND COEFFICIENT OF CONDITION, K , OF IOWA
SMALLMOUTH BLACK BASS, JULY TO SEPTEMBER, 1947

Average Standard Length in Mm.*	Average Total Length in Inches†	Number of Fish	Average Weight in Grams	Calculated Weight in Grams‡	Weight in Ounces	Average K
103.....	5.0	4	24	26	0.9	2.57
120.....	5.9	3	44	42	1.5	2.56
137.....	6.5	4	64	63	2.2	2.42
159.....	7.8	10	111	100	3.5	2.69
181.....	8.8	14	135	149	5.3	2.69
199.....	9.8	30	197	200	7.1	2.44
221.....	10.7	21	298	276	9.7	2.46
239.....	11.6	8	328	352	12.4	2.39
258.....	12.6	4	457	446	15.7	2.64
273.....	14.0	3	528	531	18.7	2.56
299.....	14.7	3	697	704	24.8	2.62
Total 104					Grand average 2.49	

* Fish were grouped by 20 millimeter size classes.

† Converted from standard length using ratio 1:1.24 as determined for Iowa smallmouth.

‡ $\text{Log } W = -4.8128 + 3.09353 \text{ Log } L$.

Stroud (7) reported an average K of 2.23 for 250 smallmouth bass from Norris Reservoir, Tennessee. The average K of forty-two age class III smallmouths from Coffin Creek was 2.48. This is considerably higher than that reported by Bennett (2) for smallmouths of age class III from six Wisconsin lakes (1.90-2.23).

The average K of eight fish from Lamont Creek was 2.64, of sixty-seven fish from Coffin Creek was 2.48, of eleven from Lime Creek was 2.42, and of ten from Prairie Creek was 2.40. It is of interest to note that the K values are highest in the creek with the most rapid growth, and the populations are in the same order when arranged according to K or growth rate. Bennett (2) found a reverse correlation with the slower growing smallmouth bass populations showing a higher coefficient of condition than the fast growing populations.

FOOD

Most of the data published on the food habits of smallmouth black bass are from lakes and are not directly comparable to those obtained in examining the stomachs of ninety-five bass from Iowa small streams (Table 6). All such studies do show that the staple foods for the mature smallmouth are crayfish and minnows. Surber (8) has contributed a comprehensive quantitative study of available food in relation to stomach contents of the smallmouth in three eastern streams. He found

TABLE 6
FOOD OF NINETY-FIVE SMALLMOUTH BLACK BASS FROM SEVEN SMALL IOWA STREAMS

	Food Item	Number of Stomachs Containing Item	Percentage of Occurrence	Total Number of Items
Arthropods				
Crustacea.....	Crayfish	29	30.5	35
Insecta.....	Insects	20	20.1	88
	terrestrial	12	12.6	21
	aquatic	8	8.4	67
Vertebrates				
Pisces.....	Fish	37	38.9	41
	minnows	26	28.4	29
	sunfish	1	1.0	2
	darters	1	1.0	1
	madtoms	1	1.0	1
	lampreys	1	1.0	1
	fish remains	7	7.4	7
Amphibia.....	Frogs	2	2.1	2
Aves.....	Birds	1	1.0	1
Empty Stomachs.....		31	32.6	
Total.....				167

that in the Cacapon River the smallmouth took tiny midges and other small food items because of a shortage of forage fish. The same general conditions existed in the South Branch of the Potomac River. The percentage of incidence of empty stomachs in these streams was low while that of the Shenandoah was rather high. The viscera of Shenandoah smallmouth were covered with fat which would allow periods of fasting. In Coffin Creek (Table 7), a fairly high percentage of the

TABLE 7
FOOD OF SMALLMOUTH BLACK BASS FROM THREE STREAMS IN VIRGINIA*
AND COFFIN CREEK IN IOWA

Stream	Percentage Empty	Percentage Containing	
		Crayfish	Fish
Cacapon River.....	13.5	12.5	26.0
South Branch Potomac River.....	14.6	12.5	20.8
Shenandoah River.....	20.8	8.5	56.6
Coffin Creek.....	34.4	22.6	37.7

* Surber, 1941.

bass which were taken had empty stomachs, but the viscera were covered with a layer of fat and the fish were in good condition. All of the streams in this study supported large populations of minnows and crayfish.

FISHING INTENSITY AND CATCH

A total of 115.17 man-hours was spent angling during July, August, and September of 1947. Thirty-seven periods of fishing averaging 3.11 hours in duration were spent in the field with an average catch of 2.81 fish per trip (range, 0 to 13). The catch-per-hour and the average size of the fish taken did not diminish as the season progressed (Table 8). Fishing pressure was concentrated on Coffin Creek during all three months, and about the same amount of time was spent angling in other streams each month in an effort to maintain fishing intensity at the same level. Lamont Creek bass had the greatest average total length at capture, but the catch-per-hour was the lowest of all streams (Table 9). Observation, as well as fishing, indicated a low population density in Lamont Creek in 1947. Coffin Creek, Lime Creek, Prairie Creek, and the Maquoketa River near Dundee were observed to have large populations of smallmouth and in all these streams the catch-per-hour was high (Table 9).

Forty-eight (46 per cent) of the 104 smallmouth taken in 1947 were of legal length, over ten inches. Twenty-six of the fifty-six smallmouth under legal length were less than one inch short. Observation, in addition to the angling, indicated there were few bass larger than those caught in the sections of the stream studied.

TABLE 8
FISHING INTENSITY AND CATCH BY MONTH OF SMALLMOUTH BLACK BASS
FROM SEVEN SMALL IOWA STREAMS, 1947

Month	July	August	September	Totals
No. of fish.....	31	37	36	104
Angling hours.....	44.09	38.25	32.83	115.17
Catch per hour.....	0.72	0.97	1.09	0.93
Size range in inches (total length).....	4.7-13.6	5.9-15.1	5.7-13.2	4.7-15.1
Average total length.....	9.2	10.2	9.6	9.70
No. of trips.....	15	12	10	37
Catch per trip.....	2.07	3.08	3.60	2.81

In many localities, fishermen believe that bass will strike better in early morning or late afternoon than at other times. Records were kept of the catches at various times of the day, and no relationship between time of day and success of angling could be detected. Bass were taken at any hour from 5 A.M. to 8 P.M. The highest catches per hour were in midday, but the differences were probably not enough to be significant. No correlation could be detected between success of fishing and air and water temperatures, nebulosity, or velocity and direction of wind.

DISCUSSION

All but one of the 104 smallmouth collected from seven small Iowa streams in 1947 were four years of age or younger. The one exception was a fish of age class VII taken in Prairie Creek. Observations of bass in these streams also indicated an extreme scarcity of large fish which would presumably be older than age class IV. This scarcity of older

TABLE 9
FISHING INTENSITY AND CATCH BY STREAMS OF IOWA SMALLMOUTH BLACK BASS, 1947

Stream	No. of Fish	Catch Per Hour	Total Length Average	Percentage of Catch Over 10 In.
Lamont Creek.....	8	0.31	11.5*	75
Prairie Creek.....	11	1.04	10.6	45
Coffin Creek.....	67	1.07	9.4	42
Lime Creek.....	11	1.20	9.3	27
Maquoketa River.....	5	0.91	9.5	60

* Six of the smallmouth from Lamont Creek were over twelve inches total length.

fish was apparent in all of the small streams investigated. It has been remarked by fishermen that the fish in these streams never seem to "grow up," and the majority of the fish taken are just above or just below the legal size limit of ten inches. Since fishermen are not interested in the number of fish present but in the size and the number of fish caught, fishing pressure is not excessive in these streams. Fifty-seven fish were removed from a 2.5-mile section of Coffin Creek by the author in 1947. Counts of adult smallmouth, made throughout the fishing season of 1947 along this section of Coffin Creek, ranged from fifty-nine to one hundred adult bass. The last count made on the 17th and 18th of September was seventy-five adult smallmouth. The catch-per-hour actually increased as the season progressed (Table 8) for all streams combined, and the average total length of these fish did not decrease. This would indicate that fishing pressure is not responsible for the absence of older fish; and it seems incredible that the drastic reduction of fish over four years of age is due to natural mortality, since the life span of the smallmouth usually extends well beyond five years.

It is probable that there is a downstream movement as the smallmouth grow, and that the older fish move into the larger streams.

These small streams offer excellent spawning conditions today, as they always have, but there is a definite shortage of suitable pool habitat and shelter for larger fish. During the summer of 1947 many pools in Coffin Creek were completely filled by sand, and, as water levels fell, many shallow pools were not suitable for larger smallmouth. This reduction in pool area caused a concentration of the bass in the few existing pools, and on two occasions seven bass were taken from one small pool.

Coffin Creek and Lamont Creek are both tributaries of the Maquoketa River and enter it a few miles apart. The smallmouth from Lamont Creek showed more rapid growth (Table 2) and greater average size (Table 8). Possible competitive species present in this stream were rainbow trout (*Salmo gairdnerii*), brown trout (*Salmo trutta*), and a dense population of very large creek chubs (*Semotilus atromaculatus*). All three species were taken while angling for smallmouth and the stomachs of several large chubs contained both fish and crayfish. White crappie (*Pomoxis annularis*), rock bass (*Ambloplites rupestris*), and bluegill (*Lepomis macrochirus*) were present in both streams. The water temperature range was slightly greater in Coffin Creek (73° to 79°F.) than in Lamont Creek (70° to 73°F.) during the hottest part of the summer, August 10 to September 15. Field chemical analyses gave almost identical results. The only apparent difference in the two streams was the population density of the smallmouth and other species. Lamont Creek had a low density compared to that of Coffin Creek. The bass in Coffin Creek, Lime Creek, and Prairie Creek would probably grow faster if fewer fish were present. There is, in general, an abundance of food in all these streams, with crayfish and several species of minnows very plentiful; but the concentration of the bass in the pools at low water stages increases the difficulty of obtaining this food.

SUMMARY AND CONCLUSIONS

1. The study of the smallmouth black bass was based on a total of 116 specimens collected from 1941 to 1947. These fish represent collections from eight streams and three lakes in Iowa.

2. The body-scale relationship can be represented as a linear regression with a Y-intercept on the standard length axis of 41 millimeters.

3. The maximum annual increase in length occurred during the first year, but the annual increment in weight increased as the fish grew older.

4. There was no significant difference in the growth rate of male and female smallmouth of age class III from Coffin Creek.

5. The length-weight relationship of 104 stream smallmouth can be expressed by the empirical formula:

$$\text{Log } W = -4.8128 + 3.09353 \text{ Log } L$$

Where W = weight in grams and L = standard length in millimeters.

6. The average coefficient of condition (K) for 116 Iowa smallmouth was 2.49, which is higher than that reported from several other areas.

7. There was an apparent correlation between the growth rate and the value of K in four streams from which eight or more specimens were taken.

8. Both male and female bass mature, before the end of their third year, at a total length of less than about nine inches.

9. Smallmouth black bass feed chiefly on crayfish and minnows.

10. The average catch was 0.9 fish per man-hour for a total of 115.17 hours of fishing. The catch per man-hour increased as the season progressed.

11. Forty-six per cent of the 104 smallmouth caught were over the legal total length of ten inches. The average size of the smallmouth taken during July, August, and September was nearly constant.

12. Smallmouth may be taken at any hour of the day with a combination of the proper lure and method of fishing.

13. Over 99 per cent of the smallmouth taken in the small streams by angling were four years of age or younger.

14. There may be a downstream drift of older and larger smallmouth in the small streams, which could explain the absence of older fish in these streams.

15. There is a shortage of suitable habitat for large smallmouth in the small streams investigated.

16. A decrease in the population density of smallmouth in the small streams would probably increase the growth rate of the remaining fish.

LITERATURE CITED

1. BECKMAN, WILLIAM G.
1949. The rate of growth and sex ratios for seven Michigan fishes. *Amer. Fisheries Soc. Trans.* 76:63-81.

2. BENNETT, GEORGE W.
1938. Growth of the smallmouth black bass, *Micropterus dolomieu* Lacépède, in Wisconsin waters. Copeia No. 4:157-70.
3. CARLANDER, KENNETH D. AND LLOYD L. SMITH, JR.
1944. Some uses of the nomograph in fish growth studies. Copeia No. 3:157-62.
4. DOAN, KENNETH H.
1940. Studies of the smallmouth bass. Jour. Wildlife Management 4:241-66.
5. ESCHMEYER, R. W.
1940. Growth of fishes in Norris Lake, Tennessee. Jour. Tenn. Acad. of Sci. 15:329-41.
6. FULLER, JOHN L. AND GERALD P. COOPER
1946. A biological survey of the lakes and ponds of Mount Desert Island, and the Union and Lower Penobscot River drainage systems. Maine Dept. Inland Fisheries and Game. Fish Survey Report No. 7:97-122.
7. STROUD, RICHARD H.
1948. Growth of the basses and black crappie in Norris Reservoir, Tennessee. Jour. Tenn. Acad. of Sci. 23:31-99.
8. SURBER, EUGENE W.
1941. A quantitative study of the food of the smallmouth black bass, *Micropterus dolomieu*, in three eastern streams. Amer. Fisheries Soc. Trans. 70:311-34.
9. TESTER, ALBERT L.
1932. Rate of growth of the smallmouthed black bass *Micropterus dolomieu* in some Ontario waters. University of Toronto Biol. Sci. Studies. Fish Res. Lab. Publ. 47:206-21.

FISHERIES INVESTIGATIONS ON TWO ARTIFICIAL LAKES IN SOUTHERN IOWA

I. LIMNOLOGY AND VEGETATION¹

WILLIAM M. LEWIS

Department of Zoology and Entomology, Iowa State College

Received July 8, 1949

Red Haw and East Lake are two eighty-acre, artificial impoundments located near Chariton, Iowa. They are situated in the same valley in such a manner that overflow water from Red Haw goes directly into East Lake. A fisheries investigation was conducted on these waters from March 26 to September 22, 1948. In the course of this work, striking differences in the presence and abundance of higher aquatic plants were noted. The present paper presents a description of the lakes and a discussion of the plant life in each.

DESCRIPTION OF RED HAW LAKE

Red Haw Lake (R-2W, T-2N, Sec. 28, 33, and 34) is a part of Red Haw Hill State Park and is used entirely for recreational purposes. It was constructed in 1935 and stocked with fish in 1936. The watershed is well protected from soil erosion and the shore line is quite irregular. The maximum water depth is slightly more than thirty feet. Approximately 90 per cent of the lake is deeper than seven and one-half feet, which is the maximum depth limit of the higher aquatic plants in the lake. Red Haw gets its water supply entirely from surface runoff. During periods of prolonged heavy rainfall and usually in the spring, there is a small overflow. After April, 1948, no overflow took place during the period of field investigations.

Temperature and oxygen records show that in mid- and late summer the lake has a well-established thermocline. From the end of March through the middle of April, the temperature at twenty-five to thirty-one feet was the same as the surface temperature. On March 29 the surface temperature was 48.8°F. and at thirty feet it was 45.0°F. On April 14

¹Project 42 of the Iowa Cooperative Fisheries Research Unit, sponsored by the Industrial Science Research Institute of Iowa State College and the Iowa State Conservation Commission, with the cooperation of the United States Fish and Wildlife Service.

This paper is a part of a thesis submitted to the graduate faculty of Iowa State College in partial fulfillment of the degree of Doctor of Philosophy, under the direction of Dr. Kenneth D. Carlander. The writer wishes to express his appreciation to Dr. J. M. Aikman and Dr. H. M. Harris for their suggestions, and to Dr. Ada Hayden for aid in the identification of the plants. The writer is also indebted to his wife, Sue D. Lewis, and to Tom English for aid in the field work.

the surface temperature was 52.0°F. and at twenty-eight feet it was 51.0°F. By May 4 thermal stratification had become established. At this time the surface temperature was 64.5°F. whereas the reading at twenty-five feet was 57.5°F. After May 4 the surface temperature continued to increase to a maximum of 86°F. on July 13. The bottom temperature became stabilized at 59°F. By late October stratification had disappeared, and the water was again the same temperature at the surface and bottom.

During July and August the epilimnion extended down to about eight feet. The lower limit of the thermocline was at or very near

TABLE 1
CONCENTRATIONS OF DISSOLVED OXYGEN AND CARBON DIOXIDE IN RED HAW LAKE,
CHARITON, IOWA, 1948

Date	Depth	Oxygen*	Carbon Dioxide†
	(feet)	(p.p.m.)	(p.p.m.)
3-29.....	18	12.8	4.5
3-30.....	28	11.6	3.0
4-12.....	Surface	7.9	2.8
	26	9.7	2.0
9-4.....	Surface	9.3	0.0
	31	0.0	22.2
9-7.....	Surface	8.3	0.0
	27	0.0	11.0
10-23.....	Surface	7.6	12.2
	30	7.3	18.5

* Oxygen determinations by Winkler technique.

† Carbon dioxide determinations by titration with sodium hydroxide to phenolphthalein end-point.

the bottom. Without doubt, the high banks and the irregular shape of the lake with the accompanying reduction of wind action accounted for the shallow epilimnion.

In the spring there was ample oxygen in the deeper water to support fish life (Table 1). In August, however, oxygen was absent at twenty-five to thirty feet. Also at this time the free carbon dioxide had reached a concentration above ten p.p.m. By October 23, when thermal stratification had disappeared, the oxygen concentration became the same at both top and bottom, but the free carbon dioxide content remained high.

The pH of the water averaged around 7.6 in the spring, but in late summer it became slightly less alkaline in the deep water and slightly more alkaline at the surface.

Transparency of the lake was determined by recording the depth at which a Secchi disc was lost from sight (Table 2). In the early spring, transparency was low, but in May the water was clear. In the summer the turbidity again became more pronounced and thereafter showed

only minor fluctuations until October. The turbidity in spring was due primarily to silt which was whipped up by wave action along the banks. During this period the shallow water areas were extremely muddy; but later in the season strong winds became less prevalent, and submerged and floating plants buffered the wave action. Throughout the remainder of the summer the important changes in turbidity were due to phyto-

TABLE 2
SECCHI DISC READINGS IN RED HAW LAKE, CHARITON, IOWA, 1948

Date	Secchi	Date	Secchi	Date	Secchi
	(cm.)		(cm.)		(cm.)
3-26.....	50.0	4-29.....	125.5	5-19.....	173.0
3-29.....	52.5	5-4.....	213.0	5-23.....	185.0
3-30.....	60.5	5-5.....	213.0	5-27.....	204.0
4-7.....	84.0	5-6.....	143.5	5-31.....	185.0
4-8.....	88.0	5-7.....	167.0	6-4.....	151.5
4-9.....	81.5	5-8.....	180.0	7-13.....	180.0
4-12.....	91.3	5-11.....	209.0	8-21.....	80.5
4-14.....	90.5	5-15.....	141.0	10-23.....	240.0

plankton. The clear water in October was the result of the disappearance of phytoplankton.

VEGETATION OF RED HAW

During spring and early summer, very few higher aquatic plants were evident. However, by mid- and late summer a distinct band of them had formed around practically the entire lake. The composition of this vegetation was quite constant, but the width of it varied according to the extent of shallow water. Four species made up the band, and for the most part each species was most abundant within a specific depth zone of water. Starting at the water's edge and extending out to a depth of eighteen inches, *Potamogeton nodosus* Poiret (*P. americanus* C. & S.) formed a dense mat of floating leaves.

Najas guadalupensis (Spreng.) Morong. formed the second zone. It occurred in a thin stand among *P. nodosus* of the first zone, and in a dense stand from the depth limit of this plant out to the three-foot depth. Although the upper part of *N. guadalupensis* reached the surface, it was mostly submerged and formed a dense mass below the surface.

Anacharis occidentalis (Pursh) Victorin was found at the depth limit of *N. guadalupensis* out to a depth of five feet. *A. occidentalis* was similar in growth habit to *N. guadalupensis* but quite often was totally submerged and thus left a zone of open water near the surface between the three- and five-foot contours.

Commencing at the five-foot depth and extending out to a depth of seven and one-half feet, *Potamogeton pusillus* L. var. *tenuissimus* occurred in almost pure stand. This plant formed the last zone of the band of vegetation surrounding the lake. It grew largely submerged, but the fruiting branches and a few of the leaves reached the surface. The growth was more open and weaker than that of the two submerged species mentioned above.

The fingerlings, and in some cases the yearlings, of all the species of fish present in the lakes were to be found almost exclusively in the shelter afforded by the zones of vegetation. Seining operations indicated the third and, in some cases, the fourth zones to be most frequently used by the smaller fishes. At the edge of the outer zone, fly fishing for largemouth black bass was exceptionally good.

Aside from the dominant species of plants, there were others which occurred in scattered beds and in some cases exerted local control. The principal species concerned were *Heteranthera reniformis* R. & R., *Jussiaea diffusa* Forsk., *Alisma plantago-aquatica* L., and *Pontederia cordata* L. The following species were present but quite scarce: *Ammannia coccinea* Roth., *Ceratophyllum demersum* L., and *Sagittaria* spp. The latter were too immature for identification.

In July, August, and September, Red Haw Lake had an almost continuous bloom of blue-green algae which reached such densities as to give the water in quiet coves a syrupy consistency. Associated with this condition there was a dense algal scum covering the water surface in the more sheltered areas.

DESCRIPTION OF EAST LAKE

East Lake (R-21W, T-72N, Sec. 27) was constructed in 1915. It serves as the city water supply for the town of Chariton. The surface area varies somewhat with water levels but averages about eighty acres.

Approximately half of the watershed close to the lake is protected from erosion by forested areas or heavy brush, and most of the other half is covered with grasses and weeds.

East Lake gets its water supply primarily from surface runoff, but any overflow that takes place at the Red Haw spillway goes directly into East Lake. During 1948 and reportedly in other years, there was some water loss over the East Lake spillway in the spring. As the summer advanced, the water level dropped well below the spillway level.

The lake is long and rather narrow. Except for a long arm stretching to the east, irregularities of the shore line are few and wind action is pronounced.

Maximum depth in the spring was twenty-five feet, but by the end of summer it was only nineteen feet. The six-foot drop was the result of evaporation and of draw-off by the city water works. The extent of shallow water varies with the water level, but at least in the spring, when the water covers broad silt beds, East Lake is characterized by more shallow water than is Red Haw.

There was some thermal stratification in the lake during the summer, but it was not so pronounced as in Red Haw Hill Lake. Throughout most of April the water was the same temperature at all levels. Later in April the surface temperature was higher than that at nineteen to twenty-five feet of depth. On July 6 the surface temperature was 88°F. and that at nineteen feet was 67°F. On October 23 the temperature was again the same at all levels.

On April 5 the oxygen concentration was the same at all depths, but in September the concentration at the bottom was below that at the

TABLE 3
CONCENTRATIONS OF DISSOLVED OXYGEN AND CARBON DIOXIDE IN EAST LAKE,
CHARITON, IOWA, 1948

Date	Depth	Oxygen	Carbon Dioxide
	(feet)	(p.p.m.)	(p.p.m.)
4-5.....	Surface	12.0	2.6
	16 "	12.0	1.9
9-7.....	Surface	7.7	1.0
	19	1.9	22.5
10-23.....	Surface	11.0	0.0
	19.5	9.8	2.5

surface and also below the five p.p.m. considered desirable for fish.

The pH in the spring was 7.6 at the surface and at sixteen feet. Later in the season, the lower water became slightly less alkaline and the surface water slightly more alkaline.

East Lake showed a high spring turbidity due to wave action along the shore line. After the strong winds of March and April were over, the transparency of the water increased, but on two or three occasions the transparency again decreased as a result of an unexplained black coloration of the water.

To control phytoplankton, East Lake was treated periodically with copper sulfate by the personnel of the city water supply department. The frequency and amount of applications varied with the need. Usually 500 to 800 pounds were used at each application. It was distributed by being placed in burlap bags and towed around the lake and, at times, across the center of the lake. With the exception of a growth of *Spirogyra* sp. in early spring before copper sulfate had been used, the water never showed a green coloration nor was there any other indication of algal growth.

VEGETATION OF EAST LAKE

East Lake had a band of vegetation extending around the shore line. The width of this band varied with the water depth.

The first shoreward zone of vegetation was composed of a mixture of *Sagittaria* spp., *Ammannia coccinea*, and *Potamogeton nodosus*. This zone was from the water's edge to a depth of eight inches.

Potamogeton nodosus formed the second zone. This plant was also found in the first zone but grew beyond the depth limit of the first zone out to the four-foot depth. The second zone formed a wide margin around the lake. *P. nodosus* has broad leaves which float on the surface. This zone was thus covered by a mat of floating leaves beneath which the water was quite open. This open yet sheltered water was a favorite haunt of adult largemouth black bass, warmouth, yellow perch, and bluegill.

Potamogeton pectinatus L. was found in large beds. Where present it formed a third zone which started at a depth of three and a half to four feet and extended out to six feet. The growth form of this plant makes it quite important from a fisheries standpoint. The plant is largely

TABLE 4
SECCHI DISC READINGS IN EAST LAKE, CHARITON, IOWA, 1948

Date	Secchi	Date	Secchi
	(cm.)		(cm.)
4-2.....	50.9	5-3.....	72.0
4-5.....	50.0	6-21.....	96.0
4-6.....	59.0	7-3.....	200.0
4-16.....	68.5	7-6.....	224.0
4-19.....	60.0	8-19.....	128.5
4-30.....	84.5	10-13.....	121.5

submerged and forms dense clusters between which there are openings, easily penetrable by larger fish. Seine hauls through beds of this plant would often produce bass fingerlings when they were hard to obtain in other habitats. Fly fishing over these beds for the larger bass was also quite profitable.

In addition to the above species, *Eleocharis obtusa* (Willd.) Schultes and *Typha latifolia* L. occurred in one or two limited areas.

In passing, it is interesting to note that, during mid- and late summer, stomach analyses showed the bluegill to be feeding on the narrow-leaved pond weeds. To some extent the channel catfish also fed on these plants.

As in Red Haw, it was not until midsummer and later that the plant zones were clearly established. After once becoming established there was little change except for a slight increase in the growth of *Sagittaria* spp.

SUMMARY AND COMPARISON OF RED HAW HILL LAKE AND EAST LAKE

A comparison of Red Haw and East Lake is of particular interest from the standpoint of the ecology of plants and animals, since the two lakes lie in the same valley and are similar in size, depth, and origin.

Furthermore, during spring rains, Red Haw overflows directly into East Lake. On the other hand, the lakes differ in several definite ways. The general and limnological differences are as follows:

EAST LAKE	RED HAW
Constructed 1915	Constructed 1935
Treated periodically during summer with copper sulfate	Not treated
Used for city water supply	Water loss principally through evaporation
Lake bottom gently sloping	Lake bottom relatively steep at most points
Clay content of soil relatively high	Soil high in organic matter
Much of shore line open	Most of shore line shaded
Wave action pronounced	Wave action less pronounced

The major differences in plant growth were:

1. *Potamogeton pectinatus*, one of the most abundant species in East Lake, was not found in Red Haw.

2. *Anacharis occidentalis* and *Potamogeton pusillus* var. *tenuissimus*, two of the most abundant species in Red Haw, were not found in East Lake.

3. *Najas guadalupensis*, very abundant in Red Haw, was scarce and appeared stunted in East Lake.

4. There were one or two large beds of *Pontederia cordata*, *Heteranthera reniformis*, and *Jussiaea diffusa* in Red Haw, but none of these species was found in East Lake.

5. *Sagittaria* spp. and *Ammannia coccinea* were common in East Lake, yet rare in Red Haw.

6. Phytoplankton blooms were almost continuous in Red Haw, but there was no evidence of heavy algal growth in East Lake.

THE BIONOMICS OF *DERMESTES MACULATUS* DEG.

I. OVIPOSITION, LONGEVITY, PERIOD OF INCUBATION¹

JOHN K. SCOGGIN AND OSCAR E. TAUBER

*From the Department of Zoology and Entomology
Iowa Agricultural Experiment Station*

Received July 15, 1949

Dermestes maculatus De Geer² (Coleoptera, Dermestidae) has been the subject of numerous entomological reports because of its ravages of products of animal and plant origin. Injury attributed to *D. maculatus* includes extensive feeding by the larvae, and the tunneling activity of the last instar larvae into any available substance in an attempt to find protection during the pupal stage. The adults cause only slight feeding damage although they consume the same materials as the larvae. Nevertheless, their presence in stored foodstuffs may make large quantities of materials unfit for commercial use.

The insect was first described by De Geer in 1774 and has since been recorded from many parts of the world. It is especially attracted to hides and skins, and has thus built up large populations in semi-tropical regions where hides are collected for shipment to other countries, and where environmental conditions are ideal for propagation. *D. maculatus*, consequently, has acquired the common name of "hide beetle" or "leather beetle." The larvae attack skins from the flesh side and, in cases of heavy infestation, perforate the skins to such an extent as to render them valueless. Distant (4) reported that a shipment of hides from China to England had been damaged 15 to 20 per cent of its value.

Lintner (10) recorded that this dermestid so ravaged the furs of the Hudson's Bay Company in its storehouse in London at one time that a reward of 20,000 pounds was offered for an effective means of control. Jones (7) reported the occurrence of this species on goat skins from Russia, South Africa, Turkey, Arabia, and South America. Even though some of the skins were heavily salted or poison cured, they were not exempt from attack.

Riley (11) cited two instances in which this insect was involved in damage to manufactured boots and shoes.

¹ Journal Paper No. J1665 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 1102.

² This insect is also known as *Dermestes vulpinus*. However, as pointed out by Barber (Bull. Brooklyn Ent. Soc. 37:174, 1942), the name *maculatus* has clear priority.

Injury to dried fish was recorded by Illingworth (6) in Hawaii, and by Kimura and Takakura (8) in Japan.

The burrowing of last instar larvae in seeking concealment for pupation has resulted in several instances of peculiar damage. Bowerbank (1) reported the case of a ship, transporting bones, horns, and hoofs from Brazil to England, in which the larvae migrated from this cargo and honeycombed the ship's mast to such an extent as to endanger its safety. According to Stephens (14), infestations were so heavy at times on ships carrying skins and bones that wooden vessels were rendered unseaworthy by larval tunneling. Robinson (12) recorded that in the hoof-drying room and bone-fertilizer storerooms of a St. Paul packing plant, areas of the woodwork as large as a foot square and one to two inches deep were honeycombed.

Bowerbank (1) also exhibited samples of cork from a twelve ton cargo which had been heavily damaged by different stages of the insect; and in this case, also, the vessel was carrying bones in its cargo. Snyder (13) reported that larvae of the "hide beetle" have bored into lead wired telephone fuses, and thereby interrupted service and necessitated replacement of damaged parts.

MATERIALS AND METHODS

The original specimens of *Dermestes maculatus* used in these experiments were collected in the fall of 1946 at Waterloo, Iowa, where the various stages of the insect were infesting fish meal stored in sacks. The source of the infestation was not determined, but it is probable that the insects were present when the meal was shipped from California. Since mature larvae were seen migrating from the fish meal, it was feared that the infestation would spread to soybean meal stored in adjoining rooms.

In the laboratory, the larvae were reared in gauze-covered battery jars filled to a depth of several inches with fish meal. The period of larval development was decreased when the jars were held at about 30°C. and the fish meal moistened daily. Care was taken to prevent the meal from becoming so moist that molds would grow. When the medium began to decompose, the larvae were changed to other jars with a new supply of fish meal. Because the larvae of *D. maculatus* consume the naked and unprotected pupae, the latter were removed daily from the cultures to a petri dish. This also made it possible to collect adults of known age, some to be used for oviposition studies, and others to provide eggs for various tests.

For the oviposition studies, a male and female were removed from the pupal dish on the day of emergence and transferred to a petri dish with a small amount of fish meal. The sexes are relatively easy to separate. The male has a more slender abdomen and the penultimate abdominal sternum has a median non-pubescent space in which is situated one or more minute spines. A small piece of absorbent cotton was placed in the dish with the beetles, and this was sprayed daily with

water to provide the moisture needed for optimum oviposition conditions. The fish meal and cotton were examined daily for eggs. If the fish meal just covered the bottom of the petri dish, most of the eggs would be deposited in the cotton and could be easily collected by pulling the cotton strands apart. Eggs deposited in the meal were removed by use of a moistened brush. In case the male died prior to the completion of the female oviposition period, or if the first male was suspected of being imperfect, a new male was added. In order to determine if repeated matings were necessary to produce the normal oviposition, a male and female were confined to a petri dish for a period of ten days, after which the male was removed. Daily oviposition was noted and, after the female failed to oviposit for a period of at least sixteen days, a new male was added.

In order to obtain a sufficient number of eggs for incubation studies, the males and females were segregated upon emergence. When a large number of adults had accumulated, the sexes were confined to a petri dish with moist cotton and fish meal, ground to a fineness so as to pass through a U. S. No. 40 sieve, 35 meshes per inch. Within a few days a large number of eggs could be obtained. To collect eggs deposited during a four-hour period, the number of eggs was increased by holding the beetles in an empty petri dish for at least twelve hours prior to placing them with ground fish meal. At the end of the oviposition period, the beetles were taken out of the dish and the eggs collected by sifting the fish meal through a No. 40 sieve. The eggs to be incubated were chosen at random from the collected eggs, which differed in age by not more than four hours. Incubated eggs were checked at four-hour intervals and the mid-point of the period recorded as the time of hatching. Eggs not needed in incubation studies were hatched in a petri dish to maintain the colony, or were used in the tests to study the larval and pupal development.

Unless otherwise specified, the above studies were conducted at 32°C. and 70 per cent relative humidity. The humidity was regulated by the use of different concentrations of potassium hydroxide as reported by Buxton (2). Eggs to be incubated at a saturated humidity were placed in a desiccator over distilled water to which 0.3 per cent phenol had been added to prevent the growth of molds.

OVIPOSITION STUDIES

A series of ten pairs of beetles was studied to determine the reproductive potential of *Dermestes maculatus*. The temperature was maintained at 32°C., and moisture was provided daily by a wad of absorbent cotton sprayed with water and placed in the petri dish with each pair. The cotton also presented an oviposition stimulus and most of the eggs were placed among the fibers. Another series of ten pairs was studied to determine the necessity of repeated matings.

A summary of the data on the oviposition of ten pairs of beetles is given in Table 1. The period from emergence to the production of

fertile eggs varied from four to ten days with an average of seven days. In some cases infertile eggs were deposited for several days prior to the beginning of normal oviposition. Infertile eggs were characterized by fragility and irregularity of shape. One female, not included in Table 1 and caged with a dwarf male, produced only infertile eggs over a period of thirty-two days and died forty-six days after emergence.

The smallest number of eggs laid by an individual female was 455, deposited over a period of fifty-six days. The largest number of eggs recorded was 1,274, over a period of sixty-six days. The oviposition period of the ten females ranged from forty-one to eighty-two days with an average of sixty-one days. There were two to thirty-six days,

TABLE 1
OVIPOSITION BY TEN FEMALES OF *Dermestes maculatus* DEG. AT 32°C.
AND IN A HUMID ENVIRONMENT

Female No.	Preoviposition Time in Days	Oviposition Period in Days	Days Without Oviposition	Days Ovipositing	Eggs Deposited	Postoviposition Period in Days
1.....	4	58	10	48	794	7
2*.....	4	82	36	46	483	21
3.....	7	59	2	57	704	23
4.....	4	41	6	35	587	29
5.....	4	66	6	60	1,274	10
6†.....	9	47	5	42	1,143	3
7.....	4	69	8	61	932	13
8.....	9	50	8	42	658	12
9.....	10	81	19	62	659	9
10.....	10	56	19	37	455	8
Mean.....	7	61	12	49	769	14

* Male dead on seventeenth day after oviposition begun; new male added.

† Infertile eggs produced on days 4-8; new male added.

with an average of twelve days, during the oviposition period when no eggs were laid. The actual days of ovipositing varied from thirty-five to sixty-two days and averaged forty-nine days. The ten females oviposited a total of 7,689 eggs for an average of approximately 769 eggs per female. The highest number of eggs produced by a female in twenty-four hours was 79. The postoviposition period ranged from three to twenty-nine days with an average of fourteen days. One of the daily oviposition records is given in Table 2.

The results of removing the male after a ten-day mating period with the female are summarized in Table 3. The period from emergence to the deposition of fertile eggs varied from three to ten days with a mean of seven days. The eggs produced during the ten-day period before the male was removed ranged from 3 to 306 with an average of 105 for the ten females. The great difference in oviposition during this period was due to the variation in preoviposition time.

The females continued to oviposit from three to twenty-nine days after the males were removed. The average oviposition period was twenty-one days. From 64 to 426 eggs were oviposited during this time with an average of 287 for the ten females. Several of the females deposited infertile eggs near the end of this first oviposition period.

After oviposition had ceased for a minimum of sixteen days, a newly emerged male was placed with each test female. In every case except one, the females began to oviposit again within one to four days. Female No. 17 failed to oviposit after caging with the second male, and died thirty days later. This female thus had a postoviposition period of forty-six days, the longest observed among the twenty females on

TABLE 2
DAILY OVIPOSITION RECORD OF ONE FEMALE* *Dermestes maculatus* DEG. 32°C.
AND IN A HUMID† ENVIRONMENT

Date	Eggs	Date	Eggs	Date	Eggs
May 28	38	June 19	20	July 11	24
May 29	41	June 20	19	July 12	11
May 30	29	June 21	39	July 13	21
May 31	18	June 22	27	July 14	19
June 1	18	June 23	11	July 15	3
June 2	22	June 24	19	July 16	9
June 3	22	June 25	13	July 17	8
June 4	7	June 26	18	July 18	4
June 5	13	June 27	3	July 19	5
June 6	23	June 28	1	July 20	16
June 7	20	June 29	0	July 21	5
June 8	0	June 30	15	July 22	5
June 9	18	July 1	15	July 23	4
June 10	0	July 2	0	July 24	1
June 11	23	July 3	0	July 25	0
June 12	23	July 4	0	July 26	0
June 13	0	July 5	12	July 27	0
June 14	4	July 6	0	July 28	0
June 15	21	July 7	0	July 29	0
June 16	35	July 8	0	July 30	0
June 17	12	July 9	11	July 31	Died
June 18	38	July 10	11		

* Male and female emerged and were caged May 24.

† Moistened cotton provided daily.

which daily oviposition records were kept. The second oviposition period for the nine females varied from five to twenty-eight days, with a mean of eighteen days. The smallest number of eggs produced during this time was 23 for a female ovipositing over a period of ten days. The highest number produced was 361 over a period of twenty-seven days. The nine females laid an average of approximately 168 eggs during the second oviposition period. The total number of eggs laid during the two oviposition periods ranged from 323 to 808. The average for the

TABLE 3
EFFECT ON EGG PRODUCTION BY *Dermestes maculatus* DEG. OF REMOVING MALE AFTER AN INITIAL TEN-DAY MATING PERIOD

Female No.	Preoviposition Time (days)	Eggs Deposited Before Male Removed	Days Ovipositing After Male Removed	Eggs Deposited After Male Removed	Days Before New Male Added	Length of 2nd Oviposition Period (days)	Eggs Deposited During 2nd Period	Postoviposition Period (days)
11*	3	306	12	174	20	20	249	8
12	5	40	25	260	20	10	23	5
13	5	186	3	64	25	16	246	6
14	6	141	26	388	16	5	39	6
15	6	95	24	312	16	7	77	5
16	9	32	21	328	16	26	136	12
17†	8	16	29	242	16			
18	10	3	18	246	16	28	262	14
19	10	21	23	426	16	27	361	6
20	5	206	26	426	25	24	115	9
Mean	7	105	21	287	19	18	168	8

* Male emerged five days prior to female.

† Female failed to oviposit after caging with second male and died thirty days later.

nine females was approximately 574 eggs. Female No. 17 oviposited a total of 258 eggs over a period of thirty-one days after being caged with a male for ten days. The postoviposition period ranged from five to fourteen days with a mean of eight days for the nine females that had a second oviposition period. One of the daily oviposition records is given in Table 4.

LONGEVITY OF ADULTS

For the ten females comprising the study of fecundity summarized in Table 1, the longevity ranged from 59 to 107 days with a mean of approximately 81 days. The ten females that were studied to determine the effect of a shortened mating period survived from 62 to 94 days with an average of approximately 77 days. The average longevity for the twenty females was 79 days. The life span of males was about the same. The longevity of five males ranged from 55 to 99 days with an average of approximately 78 days. The individuals were kept at 32°C. and were provided with moisture daily.

A group of eighteen males and eighteen females emerging on the same day was confined with fish meal (7.5 per cent water content) as food, and maintained at 32°C. and 70 per cent relative humidity. The first deaths, one male and one female, occurred within 10 days. The 50 per cent death point was reached between 20 and 25 days, and all adults were dead within 30 days after emergence.

INCUBATION STUDIES

A summary of the results of incubation studies is given in Table 5. The range of the incubation period and time required for 50 per cent of the viable eggs to hatch out of a test lot of 100 eggs are recorded for each combination of temperature and humidity. The percentage of hatch for each environmental condition is included.

Since eggs incubated over water at the lower temperatures were attacked by molds and failed to hatch, a 0.3 per cent phenol solution was used in the high humidity tests. At 32°C. the incubation period was shortened to such an extent that the eggs were not affected by molds. After incubation at the highest humidity, a number of the larvae began to hatch but were unable to extricate themselves from the eggshell. This accounts for the lowered percentage of hatch of eggs incubated over 0.3 per cent phenol at 20°, 24°, and 28°C.

Incubation at 20°C.

Lots of 100 eggs were incubated at 20°C. and at five different levels of humidity. The shortest incubation period was 154 hours, occurring at both 20 and 40 per cent relative humidity. The longest time required for incubation was 192 hours over 0.3 per cent phenol. The range of incubation time for the four lowest humidities was approximately 24 hours, but it increased to 34 hours at the highest humidity. The time required for 50 per cent hatch of the viable eggs at the different humidity

ties varied from 162 to 176 hours. The shortest time occurred at 40 per cent humidity and the longest over 0.3 per cent phenol. The percentage of hatch was approximately constant for 20, 40, 60, and 80 per cent relative humidity. It varied from 84 to 89 per cent. The hatch of eggs incubated over 0.3 per cent phenol dropped to 56 per cent.

Incubation at 24°C.

At 24°C. the shortest incubation period was 90 hours and occurred at the highest humidity. One individual hatched at 60 per cent after 116 hours. This was the longest incubation period noted for eggs maintained at 24°C. The range of incubation periods was from 8 to 20 hours with the greatest range occurring at 60 per cent humidity. The 50 per cent hatch point was reached after 96 hours for the lowest and highest humidities; 100 hours for 40 and 80 per cent humidity; and 104 hours for 60 per cent humidity. The percentage of hatch varied from 81 to 89 per cent for the four lowest humidities and decreased to 58 per cent for eggs incubated over 0.3 per cent phenol.

TABLE 4
DAILY OVIPOSITION RECORD OF ONE FEMALE* *Dermestes maculatus* DEG. AT 32°C.
WITH MALE REMOVED AFTER A TEN-DAY PERIOD

Date	Eggs ^a	Date	Eggs	Date	Eggs
Oct. 18.....	11	Nov. 13.....	0	Dec. 8.....	7
Oct. 19.....	21	Nov. 14.....	0	Dec. 9.....	5
Male removed.....		Nov. 15.....	0	Dec. 10.....	0
Oct. 20.....	43	Nov. 16.....	0	Dec. 11.....	0
Oct. 21.....	42	Nov. 17.....	0	Dec. 12.....	3
Oct. 22.....	43	Nov. 18.....	0	Dec. 13.....	2
Oct. 23.....	14	Nov. 19.....	0	Dec. 14.....	4
Oct. 24.....	39	Nov. 20.....	0	Dec. 15.....	4
Oct. 25.....	17	Nov. 21.....	0	Dec. 16.....	3
Oct. 26.....	28	Nov. 22.....	0	Dec. 17.....	4
Oct. 27.....	16	Nov. 23.....	0	Dec. 18.....	0
Oct. 28.....	23	Nov. 24.....	0	Dec. 19.....	3
Oct. 29.....	17	Nov. 25.....	0	Dec. 20.....	5
Oct. 30.....	12	New male added.....		Dec. 21.....	3
Oct. 31.....	19	Nov. 26.....	7	Dec. 22.....	0
Nov. 1.....	12	Nov. 27.....	19	Dec. 23.....	0
Nov. 2.....	1	Nov. 28.....	9	Dec. 24.....	0
Nov. 3.....	1	Nov. 29.....	12	Dec. 25.....	0
Nov. 4.....	0	Nov. 30.....	9	Dec. 26.....	0
Nov. 5.....	0	Dec. 1.....	10	Dec. 27.....	0
Nov. 6.....	0	Dec. 2.....	6	Dec. 28.....	0
Nov. 7.....	0	Dec. 3.....	6	Dec. 29.....	0
Nov. 8.....	0	Dec. 4.....	7	Dec. 30.....	0
Nov. 9.....	1	Dec. 5.....	2	Dec. 31.....	0
Nov. 10.....	0	Dec. 6.....	0	Jan. 1.....	0
Nov. 11.....	0	Dec. 7.....	6	Jan. 2.....	Died
Nov. 12.....	0				

* Male and female emerged and were caged Oct. 9.

Incubation at 28°C.

For 100 eggs maintained at 28°C., the shortest incubation period was 64 hours. This occurred in the group incubated over 0.3 per cent phenol. The longest period required for incubation was 76 hours at both 20 and 80 per cent relative humidity. The spread of incubation periods was from 6 to 10 hours. For the five different humidities, the 50 per cent hatch point occurred at 66 hours. The percentage of hatch for the

TABLE 5
INCUBATION PERIODS AND PERCENTAGES OF HATCH OF 100 EGGS OF *Dermestes maculatus* DEG.
UNDER VARYING CONDITIONS OF TEMPERATURE AND HUMIDITY

Temperature	Percentages of Relative Humidity				Over 0.3% Phenol Solution
	20%	40%	60%	80%	
20°C.					
Range (hours).....	154-178	154-176	158-186	160-186	158-192
50% hatch (hours)....	164	162	172	168	176
Hatch.....	89%	85%	89%	84%	56%
24°C.					
Range (hours).....	92-104	96-108	96-116	96-104	90-104
50% hatch (hours)....	96	100	104	100	96
Hatch.....	89%	82%	85%	81%	58%
28°C.					
Range (hours).....	66-76	66-72	66-72	66-76	64-72
50% hatch (hours)....	66	66	66	66	66
Hatch.....	81%	83%	80%	74%	76%
32°C.					
Range (hours).....	48-56	48-56	48-52	44-48	44-52
50% hatch (hours)....	52	48	48	48	48
Hatch.....	83%	89%	90%	94%	93%

three lowest humidities ranged from 80 to 83 per cent. Of eggs incubated at 80 per cent relative humidity, 74 per cent hatched. The hatch of the eggs maintained over 0.3 per cent phenol was 76 per cent.

Incubation at 32°C.

At 32°C. the shortest incubation period was 44 hours, occurring at the two highest humidities. The longest incubation period, occurring at the two lowest humidities, was 56 hours. The range of incubation time was from 4 to 8 hours. The 50 per cent hatch point, at 20 per cent relative humidity, was reached after 53 hours. In the case of the other four humidities, the time required for 50 per cent hatch was 48 hours. The percentage of hatch increased from 83 per cent at 20 per cent humidity to 94 per cent at 80 per cent humidity. The hatch of eggs incubated over 0.3 per cent phenol was 93 per cent.

COMPARISON WITH PREVIOUSLY PUBLISHED RECORDS

The results presented in this paper are not in close agreement, in many cases, with previous reports. This must be attributed, in large

measure, to the differences in environmental conditions under which the investigations were conducted. Many of the earlier references concerning *Dermestes maculatus* do not state the conditions of nutrition, moisture, and temperature.

Illingworth (6) reported a preoviposition period of ten to eleven days for this species under the tropical conditions of Hawaii. Kreyenberg (9) determined a preoviposition period of almost a month, when the beetles were kept at a room temperature of 22°C. and given sufficient food. Riley (11), in 1885, isolated two pairs of beetles; before death, 17 eggs were oviposited in one case, and 23 in the other. He pointed out that this small number was not to be considered as the egg laying potential of *D. maculatus*. Kimura and Takakura (8) reported that the females oviposited 3-20 eggs at intervals of one to five days, and died after five or more ovipositions. According to Dick (3), beetles allowed to drink every fourth day from moist cotton-wool oviposited an average of 567 eggs over an average period of seventy-two days.

Illingworth (6) reported that the adults of *D. maculatus* in his culture were actively reproducing three months after emergence. According to Grady (5), the life span of the adults was four or five months with a reproduction period of at least two months. A period of two or three months was given by Walker (15) as the natural longevity of the adults.

Illingworth (6) reported an incubation period of three days for the eggs in Hawaii. In Japan, Kimura and Takakura (8) found that the eggs hatched in three to twelve days, depending on the prevailing temperature. Grady (5), conducting studies of this insect at 23°C. and 40 per cent humidity, noted an incubation period of three or four days.

SUMMARY AND CONCLUSIONS

1. Methods for rearing *Dermestes maculatus* in the laboratory are presented.

2. Oviposition studies were conducted with ten pairs of adults, the sexes being caged together throughout life. Another series of ten pairs was studied to determine the effect of removing the male after an initial ten-day mating period. The temperature was held at 32°C., and water was provided daily along with the oviposition stimulus of absorbent cotton.

3. Approximately seven days elapse between the time of emergence of the female and production of fertile eggs. Females ordinarily lay in excess of 700 eggs during a period of about two months, and usually live for about two weeks after cessation of oviposition. Repeated matings increase the length of the oviposition period and the number of eggs laid.

4. Males and females kept at 32°C. and provided with water daily live two to three months, with a few having a life period in excess of three months. With decreased moisture, adult longevity decreases.

5. The effect of temperature and humidity on the incubation of eggs of *D. maculatus* was studied by incubating samples of 100 eggs at each of four different temperatures and five different humidities. The tem-

peratures employed were 20°, 24°, 28°, and 32°C. The humidities were 20, 40, 60, and 80 per cent; and one batch of eggs was incubated over 0.3 per cent phenol.

6. The approximate incubation periods are as follows: seven days at 20°C.; four days at 24°C.; three days at 28°C.; and two days at 32°C. Humidity does not appreciably affect the incubation period. Temperature does not cause any appreciable change in the percentage of hatch, except in those eggs incubated over 0.3 per cent phenol. At 28°C. and lower, the percentage hatch is decreased when the humidity approaches saturation.

LITERATURE CITED

1. BOWERBANK, J. S.
1837. Exhibitions, memoirs, etc. Trans. Ent. Soc. London. Jour. Proc. Series I. 2:LX.
2. BUXTON, P. A.
1931. The measurement and control of atmospheric humidity in relation to entomological problems. Bull. Ent. Res. 22:431-47.
3. DICK, J.
1937. Oviposition in certain Coleoptera. Ann. Appl. Biol. 24:762-96.
4. DISTANT, W. L.
1877. Exhibitions, memoirs, etc. Trans. Ent. Soc. London. Jour. Proc. Series III. 25:xxii.
5. GRADY, A. G.
1928. Studies in breeding insects throughout the year for insecticide tests II. Leather beetles (*Dermestes vulpinus* Fab.). Jour. Econ. Ent. 21:604-08.
6. ILLINGWORTH, J. F.
1918. The leather beetle (*Dermestes vulpinus* Fab.), a troublesome pest of dried fish in Hawaii. Proc. Hawaii. Ent. Soc. 3:375-78.
7. JONES, F. M.
1889. *Dermestes vulpinus* in goat skins. Insect Life 2:63-64.
8. KIMURA, K. AND Y. TAKAKURA
1919. Hidara Chugai Yobo ni Kwansuru Kenkyu. Suisankoshujo Shiken Hokoku 15(1):1-32. Original not seen; abstracted in Rev. Appl. Ent. A 8:255-56. 1920.
9. KREYENBERG, J.
1928. Experimentell-biologische Untersuchungen über *D. lardarius* L. und *D. vulpinus* F. Zischr. f. Angew. Ent. 14:140-88.
10. LINTNER, J. A.
1884. The bacon beetle. Country Gent. 49:537.
11. RILEY, C. V.
1885. The leather beetle or toothed Dermestes (*Dermestes vulpinus* F.) Order Coleoptera; Family Dermestidae. Rept. U. S. Commissioner Agr. 1885:258-64.
12. ROBINSON, V. E.
1930. The mouth-parts of the larval and adult stages of *Dermestes vulpinus* F. Ann. Ent. Soc. Amer. 23:399-414.
13. SNYDER, T. E.
1926. Insect metal workers. Nature Mag. 8:277-80.
14. STEPHENS, J. F.
1837. Exhibitions, memoirs, etc. Trans. Ent. Soc. London. Jour. Proc. Series I. 2:LX.
15. WALKER, F. H.
1944. Life histories and control tests on three insect pests of skins stored in the tannery. Jour. Kansas Ent. Soc. 17:7-14.

CENTER OF FLEXURE OF BEAMS OF TRIANGULAR SECTION

R. N. Goss

From the Department of Mathematics, Iowa State College

Received August 3, 1949

I. Introduction

Consider a cylindrical beam of finite length and uniform cross-section, the lateral surface of which is free from tractions. Let one end be fixed and the other support a load W at right angles to the generators of the beam. In addition to the simple bending effect of the load, the beam in general is subject to a twist, which can be measured about any axis parallel to the generators of the beam and which vanishes about one such axis. The point of loading for which the twist is zero about the axis through the centroids of the cross-sections is termed the center of flexure. Since the problem of locating the center of flexure is essentially two-dimensional, we shall characterize the beam by the shape of a typical cross-section and make no further reference to its extent in the longitudinal direction.

When the section is triangular, the determination of the center of flexure under the most general conditions is very difficult. On specializing the geometry or the elastic properties of the beam, however, three cases become immediately tractable. One, that of the general isosceles triangle in any uniform beam, has been discussed in a forthcoming paper. The other two, which are treated here, are the case of the right triangle with the load applied parallel to the hypotenuse and that of the general incompressible triangle.

Let the plane of the section be the xy -plane and let the load W be resolved into components W_x and W_y parallel to the coordinate axes. Since the boundary is to be free from external forces, the stress components τ_{yz} and τ_{zx} must satisfy the equation

$$(1) \quad \tau_{zx} \cos(x, n) + \tau_{yz} \cos(y, n) = 0,$$

where n is the direction normal to the boundary. These stress components consist of two parts corresponding respectively to the twisting and bending effects mentioned above. When the load is applied at the center of flexure, the twist at the centroid is zero; hence to find the center of flexure (x_0, y_0) we insert the values of the flexural parts of these components at the centroid in the equation

$$(2) \quad \iint_S (x\tau_{yz} - y\tau_{zx}) dx dy = x_0 W_y - y_0 W_x,$$

which expresses the fact that the torsional couple due to the stresses is equal to the moment of the load. If the direction of the load is arbitrary, (2) is sufficient to determine x_0 and y_0 uniquely. In these cases we use the flexure functions calculated by Seth.¹

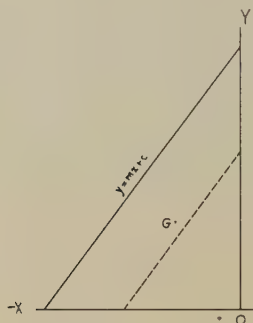


Figure 1

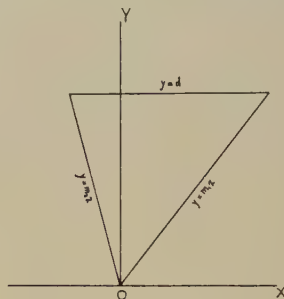


Figure 2

II. Any Right Triangle with Load Parallel to the Hypotenuse

Let the section be a right triangle (Fig. 1) with vertices at $(0,0)$, $(0,c)$, $(-c/m,0)$, and let the load W with components $W_x + W_y P_{xy}/I_x$ and $W_y + W_x P_{xy}/I_y$ parallel to the axes of x and y respectively be applied from a point (x_0, y_0) . The moments and product of inertia are referred to axes through the centroid G . The flexural terms in the stress components are in this case

$$\tau_{zx} = \frac{\partial \chi}{\partial x} - A_1 \left[\frac{1}{2} \sigma (x-\bar{x})^2 + (1-\frac{1}{2} \sigma)(y-\bar{y})^2 \right] - A_2 (2+\sigma)(x-\bar{x})(y-\bar{y}),$$

$$\tau_{yz} = \frac{\partial \chi}{\partial x} - A_1 (2+\sigma)(x-\bar{x})(y-\bar{y}) - A_2 \left[\frac{1}{2} \sigma (y-\bar{y})^2 + (1-\frac{1}{2} \sigma)(x-\bar{x})^2 \right],$$

¹ B.R. Seth, Proc. London Math. Soc., Ser. 2, 41: 325-331. 1936.

where χ is the flexure function, $\bar{x} = -c/3m$ and $\bar{y} = c/3$ are the coordinates of the centroid, $A_1 = \mu W_x/EI_y$, $A_2 = \mu W_y/EI_x$, σ is Poisson's ratio, μ is the rigidity, and E is Young's modulus. When the load acts parallel to the hypotenuse, Seth has shown that the flexure function satisfying the boundary condition (1) is given by

$$\begin{aligned}\chi = & -\frac{1}{8}A_2[2\bar{y}(1+\sigma) + c](\bar{x}^2 - \bar{y}^2) + (A_1\sigma\bar{y} - A_2\sigma\bar{x})\phi \\ & + A_1\left\{\bar{x}\left[\frac{1}{8}\sigma\bar{x}^2 + (1-\frac{1}{8}\sigma)\bar{y}^2\right] + (2+\sigma)\bar{x}\bar{y} - 2\bar{y}^2\bar{x} - \frac{1}{2}\sigma\bar{x}(\bar{x}^2 - \bar{y}^2)\right. \\ & \left.- \frac{1}{8}(1-\frac{1}{8}\sigma)(\bar{x}^3 - 3\bar{x}\bar{y}^2)\right\} + A_2\left\{\bar{y}\left[(1-\frac{1}{8}\sigma)\bar{x}^2 + \frac{1}{8}\sigma\bar{y}^2\right]\right. \\ & \left.+ (2+\sigma)\bar{y}\bar{x} - 2\bar{x}^2\bar{y} + \frac{1}{8}\sigma\bar{y}(\bar{x}^2 - \bar{y}^2) + \frac{1}{8}(1-\frac{1}{8}\sigma)(3\bar{x}^2\bar{y} - \bar{y}^3)\right\},\end{aligned}$$

where ϕ is the torsion function.

Equation (2) for determining the center of flexure is now

$$(3) \quad x_o(W_y + \frac{1}{2}mW_x) - y_o(W_x + \frac{1}{2}W_y/m) = \iint_S (x\tau_{yz} - y\tau_{zx})dxdy,$$

in which we have used $I_x = c^4/36m$, $P_{xy} = c^4/72m^2$, $I_y = c^4/36m^3$. For the integrand in the right member we have after some reduction

$$\begin{aligned}x\tau_{yz} - y\tau_{zx} = & \sigma(A_1\bar{y} - A_2\bar{x})(\bar{x}^2 + \bar{y}^2) + (1-2\sigma)(A_1\bar{x}^2\bar{y} - A_2\bar{x}\bar{y}^2) \\ & + [2(1+\sigma)(A_1\bar{x} + A_2\bar{y}) + 2A_2c]xy + \sigma(A_1\bar{y} - A_2\bar{x})(x\frac{\partial\phi}{\partial y} - y\frac{\partial\phi}{\partial x}).\end{aligned}$$

On introducing the torsional rigidity D , defined by the equation

$$(4) \quad D = \mu \iint_S (\bar{x}^2 + \bar{y}^2 + x\frac{\partial\phi}{\partial y} - y\frac{\partial\phi}{\partial x})dxdy,$$

the right member of (3) becomes

$$\begin{aligned}\sigma(A_1\bar{y} - A_2\bar{x})D/\mu + \iint_S \left\{ (1-2\sigma)(A_1\bar{x}^2\bar{y} - A_2\bar{x}\bar{y}^2) + [2(1+\sigma)(A_1\bar{x} + A_2\bar{y})\right. \\ \left. + 2A_2c]xy \right\}dxdy.\end{aligned}$$

After carrying out the integration we have

$$\begin{aligned}x_o(W_y + \frac{1}{2}mW_x) - y_o(W_x + \frac{1}{2}W_y/m) = & \frac{12\sigma Dm}{Ec^3}(m^2W_x + W_y/m) \\ & + \frac{c\mu}{5E}[(8-\sigma)W_x - (11\sigma+17)W_y/m].\end{aligned}$$

Since the direction of the load is parallel to the hypotenuse, $W_y = mW_x$, and this equation becomes

$$mx_0 - y_0 = \frac{4\sigma Dm(m+1)}{\mu c^3(1+\sigma)} - \frac{c(3+4\sigma)}{5(1+\sigma)}.$$

We cannot determine x_0 and y_0 separately, for fixing the direction of the load in this asymmetrical section uses up one of the two independent conditions necessary for their determination. When $m = 1$, this result reduces to that obtained previously for the isosceles triangle.

To complete the solution, we find as a first approximation to D by the Rayleigh-Ritz method

$$D = \frac{\mu c^4}{20m(m^2+1)}.$$

This gives as a final approximate result

$$mx_0 - y_0 = -3c/5,$$

which is independent of σ . This equation is that of the broken line in Figure 1.

III. Any Triangle and Any Direction of Load with $\sigma = \frac{1}{3}$

Let the equations of the sides of the triangle be $y = d$, $y = m_1x$, $y = m_2x$ (Fig. 2). For the load W resolved as in section II, the flexural terms in the stress components are

$$\begin{aligned}\tau_{zx} &= A_1 \left[\frac{\partial \chi_1}{\partial x} - \frac{1}{2}\sigma(x-\bar{x})^2 - (1-\frac{1}{2}\sigma)(y-\bar{y})^2 \right] + A_2 \left[\frac{\partial \chi_2}{\partial x} - (2+\sigma)(x-\bar{x})(y-\bar{y}) \right], \\ \tau_{yz} &= A_1 \left[\frac{\partial \chi_1}{\partial y} - (2+\sigma)(x-\bar{x})(y-\bar{y}) \right] + A_2 \left[\frac{\partial \chi_2}{\partial y} - \frac{1}{2}\sigma(y-\bar{y})^2 - (1-\frac{1}{2}\sigma)(x-\bar{x})^2 \right],\end{aligned}$$

and to satisfy (1),

$$\begin{aligned}\chi_1 &= \frac{d(m_1+m_2)}{2m_1m_2}(1-\frac{1}{2}\sigma)(x^2 - y^2) + \left(\frac{1}{2}d\frac{m_1m_2-1}{m_1m_2} - 2\bar{y} \right)xy + x \left[\frac{1}{2}\sigma\bar{x}^2 + (1-\frac{1}{2}\sigma)\bar{y}^2 \right] \\ &\quad + (2+\sigma)\bar{x}\bar{y} - 2\bar{y}xy - \frac{1}{2}(1-\frac{1}{2}\sigma)(x^3 - 3xy^2) + \left[\sigma\bar{y} - \frac{1}{2}d\frac{m_1m_2-1}{m_1m_2} \right]\phi, \\ \chi_2 &= \frac{1}{2}(\sigma\bar{y}-d)(x^2 - y^2) + \left[(1-\frac{1}{2}\sigma)\bar{x}^2 + \frac{1}{2}\sigma\bar{y}^2 \right]y + (2+\sigma)\bar{x}\bar{y}x - 2\bar{x}xy \\ &\quad + \frac{1}{2}(1-\frac{1}{2}\sigma)(3x^2y - y^3) - \sigma\bar{x}\phi.\end{aligned}$$

In these equations all symbols have the same significance as in section II except that $\bar{x} = d(m_1+m_2)/3m_1m_2$, $\bar{y} = 2d/3$. Proceeding as before, we find

$$x\tau_{yz} - y\tau_{zx} = A_1 \left[\left(\frac{1}{3}d - \frac{1}{2}d\frac{m_1m_2-1}{m_1m_2} \right)y^2 - 3\bar{x}xy + \left(\frac{1}{3}d + \frac{1}{2}d\frac{m_1m_2-1}{m_1m_2} \right)x^2 \right]$$

$$- \frac{1}{2} \bar{x} A_2 (x^2 + y^2) + \left[A_1 \left(\frac{1}{3} d - \frac{1}{2} d \frac{m_1 m_2 + 1}{m_1 m_2} \right) - \frac{1}{2} \bar{x} A_2 \right] \left(x \frac{\partial \phi}{\partial y} - y \frac{\partial \phi}{\partial x} \right).$$

Making use of (4) we obtain the equation

$$\begin{aligned} \frac{\mu W_x}{EI_y} \frac{d^5 (m_1 - m_2)^3}{72 m_1^3 m_2^3} - \left[\frac{\mu W_x}{EI_y} \frac{d(m_1 m_2 + 3)}{18 m_1 m_2} + \frac{\mu W_y}{EI_x} \frac{d(m_1 + m_2)}{18 m_1 m_2} \right] \frac{D}{\mu} \\ = x_0 \left(\frac{W_x P_{xy}}{I_y} + W_y \right) - y_0 \left(W_x + \frac{W_y P_{xy}}{I_x} \right). \end{aligned}$$

On using the values of I_x , I_y , P_{xy} and equating the coefficients of W_x and W_y , we obtain for the coordinates of the center of flexure

$$\begin{aligned} (5) \quad x_0 &= \frac{d(m_1 + m_2)}{3 m_1 m_2} - \frac{4(m_1 + m_2)(2m_1^2 - 5m_1 m_2 + 2m_2^2 - m_1^2 m_2^2)}{3(m_2 - m_1)^3} \frac{D}{\mu d^3}, \\ y_0 &= \frac{2d}{3} - \frac{4m_1 m_2(m_1^2 - 4m_1 m_2 + m_2^2 - 2m_1^2 m_2^2)}{3(m_2 - m_1)^3} \frac{D}{\mu d^3}. \end{aligned}$$

If we set $m_1 = -m_2 = m$, we obtain for the isosceles triangle

$$x_0 = 0, \quad y_0 = \frac{2d}{3} - \frac{m(3-m)}{3\mu d^3} \frac{D}{\mu d^3},$$

which is in agreement with the result for $\sigma = \frac{1}{2}$ obtained in the forthcoming paper, and which contains as a special case the well known result that the center of flexure coincides with the centroid in the equilateral triangle.

The solution may be completed by using Saint-Venant's approximation for D , which in this case is

$$D = \frac{9\mu d^4 (m_2 - m_1)^3}{16\pi^2 m_1 m_2 (m_1^2 m_2^2 + m_1^2 - m_1 m_2 + m_2^2)}.$$

The result in section II was seen to be independent of σ in the first approximation. In the case of the general isosceles triangle the influence of σ upon the center of flexure has been found to be negligible except when the vertical angle is small. Hence we may reasonably infer that for the general triangular section the position of the center of flexure will vary but slightly from that given by (5), whatever the value of Poisson's ratio.

TORSION OF COMPOSITE SECTIONS

L. E. PAYNE

From the Department of Mathematics, Iowa State College

Received August 3, 1949

Many methods exist whereby the Saint-Venant's torsion problem may be solved. Trefftz (1) and Seth (2) have made extensive use of conformal transformations. References to many other contributions may be found in a publication by Seth (3) and a paper by Higgins (4). More recently the analytic function theory method has been developed by a group of Russian mathematicians, led by Muschelisvili (5). Many references may be found in a paper by Sokolnikoff (6). Prager and Synge (7) have used the function space method. Hay (8) has adapted the method of images. Much work has been done on sections of isotropic materials, but very little work has been done with composite sections composed of 1) two or more different isotropic materials or 2) partly isotropic and partly anisotropic materials. Muschelishvili (9) and Ruchadze (10) have solved the problem in the case of reinforced concrete beams considered as composite sections. We propose to solve the torsion problem for beams with cross sections of the following types:

- A. Sections of two different isotropic materials,
- B. Sections, portions of which are orthotropic, the remainder being isotropic.

Numerical values for the torsional rigidities, D , of these sections are compared with those for the completely isotropic and the completely orthotropic beam of similar external section.

COMPOSITE SECTIONS OF DIFFERENT ISOTROPIC MATERIALS

Sections of only two materials will be considered. The method of solution may be easily extended to take care of sections of three or more materials. In general for the type of problem we are considering there will be an outer boundary C_1 and an inner boundary C_2 as shown in Figure 1; μ_1 and ϕ_1 will be the shear modulus and the torsion function respectively for that part of the section between C_1 and C_2 . Similarly, μ_2 and ϕ_2 will correspond to the section inside C_2 , ϕ_1 and ϕ_2 being

functions of x and y .

The stresses and deflections are defined as:

$$\begin{aligned}\tau_{xz} &= \alpha \mu_1 \left(\frac{\partial \Phi_1}{\partial x} - y \right), \\ \tau_{yz} &= \alpha \mu_1 \left(\frac{\partial \Phi_1}{\partial y} + x \right),\end{aligned}\quad (1)$$

$$u = -\alpha yz, \quad v = \alpha xz, \quad w = \alpha \Phi_1(x, y).$$

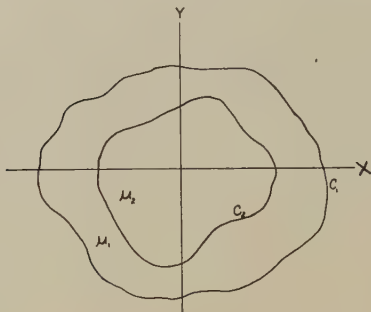


Figure 1

The following boundary conditions must be satisfied:

a. The boundary C_1 is free of shear, i.e. on C_1 , $l\tau_{xz} + m\tau_{yz} = 0$. This may be written as $\Psi_1 = \frac{1}{2}(x^2 + y^2)$, (Ψ_1 is the conjugate function to Φ_1) or $\Phi_1 = 0$, where $\Phi_1 = \Psi_1 - \frac{1}{2}(x^2 + y^2)$.

b. Across C_2 the deflection is continuous. This means that along C_2 , $\Phi_1 = \Phi_2$.

c. Across C_2 the tractions are continuous. This may be written $\mu_1 \Phi_1 = \mu_2 \Phi_2 + \text{a constant}$, on C_2 . Since we are at liberty to adjust Φ_2 so that the constant in this expression is zero, then the expression for the rigidity of the section becomes:

$$D = 2\mu_1 \iint_{A_1} \Phi_1 \, dx \, dy + 2\mu_2 \iint_{A_2} \Phi_2 \, dx \, dy. \quad (2)$$

Sections of two different types of isotropic materials may be divided into two classes. In one case C_2 is a line of shearing stress; in the other it is not:

1. C_R is a line of shearing stress

a) Concentric circles of radii a and b , $a < b$,

In this case:

$$\varphi_1 = \varphi_2 = 0, \text{ over entire section,} \quad (3.1)$$

$$D = \frac{1}{8} \pi \mu_1 b^4 - \frac{1}{8} \pi (\mu_1 - \mu_2) a^4.$$

b) Concentric ellipses of semi-major and semi-minor axes

a_1, a_2 and b_1, b_2 , with $a_1 > a_2$,

Here:

$$\varphi_1 = \varphi_2 = - \frac{a_1^2 - b_1^2}{a_1^2 + b_1^2} xy, \quad (3.3)$$

$$D = \frac{\pi \mu_1 a_1^3 b_1^3}{a_1^2 + b_1^2} - \frac{\pi a_2^3 b_2^3}{a_2^2 + b_2^2} (\mu_1 - \mu_2). \quad (3.4)$$

2. C_R is not a line of shearing stress

a) Confocal ellipses

The solution for this section (Fig. 2) involves the elliptic transformation:

$$x+iy = z = c \cosh \zeta = c \cosh (\xi + i\eta), \quad (4.1)$$

$$x = c \cosh \xi \cos \eta, \quad (4.2)$$

$$y = c \sinh \xi \sin \eta. \quad (4.3)$$

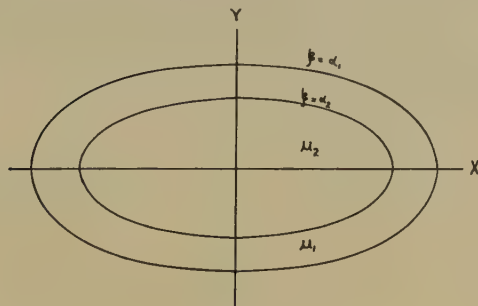


Figure 2

We may take the φ 's to be of the type:

$$\varphi_1 = - (A_1 \cosh 2\xi + B_1 \sinh 2\xi) \sin 2\eta, \quad (5.1)$$

$$\varphi_2 = - (B_2 \sinh 2\xi \sin 2\eta). \quad (5.2)$$

The boundary conditions give:

$$4d_1A_1 = c^2(\mu_2 - \mu_1)(\cosh 2a_1 - \cosh 2a_2), \quad (6.1)$$

$$4d_1B_1 = c^2\mu_1(\sinh 2a_1 - \sinh 2a_2) - c^2\mu_2(\sinh 2a_1 - \cosh 2a_2 \coth 2a_2), \quad (6.2)$$

$$4d_1B_2 = c^2\mu_1(\operatorname{csch} 2a_2 - \frac{1}{2} \cosh 2a_1 \operatorname{csch} 4a_2) + c^2d_1 \operatorname{sech} 2a_2, \quad (6.3)$$

where

$$d_1 = \mu_1 \sinh 2(a_1 - a_2) + \mu_2 \coth 2a_2 \cosh 2(a_1 - a_2).$$

$$\begin{aligned} 4MD = & \mu_1\pi(a_2^2 + b_2^2) \left[M\{a_1b_1(a_1^2 + b_1^2) - a_2b_2(a_2^2 + b_2^2)\} \right. \\ & - c^4 \left\{ 4\mu_1a_2b_2(a_2b_1 - a_1b_2)^2 + \mu_2a_2b_2(a_1^2 + b_1^2 - a_2^2 - b_2^2)^2 \right. \\ & \left. \left. - \mu_2(a_1b_1 - a_2b_2)(4a_1b_1a_2b_2 - [a_2^2 + b_2^2]^2) \right\} \right] \\ & - \mu_2\pi a_2b_2 \left\{ M(a^4 + b^4) + c^8\mu_1(a_2^2 + b_2^2 - a_1^2 - b_1^2) \right\}, \quad (6.4) \end{aligned}$$

where

$$\begin{aligned} M = & (a_2^2 + b_2^2) \left\{ 4\mu_1a_2b_2(a_1a_2 - b_1b_2)(b_1a_2 - a_1b_2) \right. \\ & \left. + \mu_2(a_2^2 + b_2^2)[(a_1^2 + b_1^2)(a_2^2 + b_2^2) - 4a_1b_1a_2b_2] \right\}. \end{aligned}$$

The torsional rigidity, D , has been determined by inserting the constants defined by equations (6.1), (6.2) and (6.3) into equations (5.1) and (5.2) and applying equation (2). The value of Φ used in equation (2) is easily obtained from the torsion function φ by the relationship $\Phi = \Psi - \frac{1}{2}(x^2 + y^2)$ where Ψ is the function conjugate to φ .

If $\mu_1 = \mu_2$ (Section completely isotropic)

$$D = \frac{\pi\mu(a_1^2b_1^2 + b_1^2a_2^2)}{a_1^2 + b_1^2}.$$

If $\mu_2 = 0$ (Section is hollow)

$$D = \frac{\pi\mu_1}{4} [a_1b_1(a_1^2 + b_1^2) - a_2b_2(a_2^2 + b_2^2) - c^4 \frac{(a_2b_1 - a_1b_2)}{a_1a_2 - b_1b_2}].$$

These are known solutions.

b) Sections bounded by eccentric circles. (Fig. 3)

We make use of the transformation

$$x+iy = z = c \tan \frac{1}{2} \zeta = c \tan \frac{1}{2}(\xi + i\eta),$$

$$x = \frac{c \sin \xi}{\cos \xi + \cosh \eta},$$

$$y = \frac{c \sinh \eta}{\cos \xi + \cosh \eta}.$$

In this case we take:

$$\Phi_1 = \sum_{n=1}^{\infty} (A_{1n} \sinh n\eta + B_{1n} \cosh n\eta) \sin n\frac{\pi}{2}, \quad (7.1)$$

$$\Phi_2 = \sum_{n=1}^{\infty} (A_{2n} \sinh n\eta \sin n\frac{\pi}{2}). \quad (7.2)$$

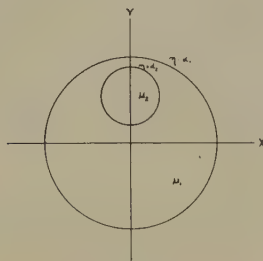


Figure 3

The boundary conditions give:

$$d_2 B_{1n} = 2c^n (-1)^n (\mu_2 - \mu_1) (\coth \alpha_1 e^{-n\alpha_1} \operatorname{sech} n\alpha_1 - \coth \alpha_2 e^{-n\alpha_2} \operatorname{sech} n\alpha_2), \quad (7.3)$$

$$d_2 A_{1n} = 2c^n (-1)^n (\mu_1 \tanh n\alpha_2 - \mu_2 \coth n\alpha_2) (\coth \alpha_1 e^{-n\alpha_1} \operatorname{sech} n\alpha_1 - \coth \alpha_2 e^{-n\alpha_2} \operatorname{sech} n\alpha_2), \quad (7.4)$$

$$d_2 A_{2n} = 4\mu_1 c^n (-1)^n (\coth \alpha_1 e^{-n\alpha_1} \operatorname{sech} n\alpha_1 - \coth \alpha_2 e^{-n\alpha_2} \operatorname{sech} n\alpha_2) \operatorname{csch} 2n\alpha_2 + 2d_2 c^n (-1)^n \coth \alpha_2 e^{-n\alpha_2} \operatorname{sech} n\alpha_2, \quad (7.5)$$

where

$$d_2 = (\mu_2 - \mu_1) \tanh n\alpha_1 + \mu_1 \tanh n\alpha_2 - \mu_2 \coth n\alpha_2.$$

$$D = 2\pi c^2 \left[\sum_{n=1}^{\infty} (-1)^n \coth \alpha_1 e^{-n\alpha_1} \left\{ \mu_1 [A_{1n} \sinh n\alpha_1 + B_{1n} \cosh n\alpha_1] - \frac{1}{2} \mu_2 \sum_{n=1}^{\infty} (-1)^n A_{2n} \right\} - 2\pi c^2 \left[\sum_{n=1}^{\infty} (-1)^n \coth \alpha_2 e^{-n\alpha_2} \left\{ \mu_1 [A_{1n} \sinh n\alpha_2 + B_{1n} \cosh n\alpha_2] - \mu_2 A_{2n} \sinh n\alpha_2 \right\} \right] - \pi \mu_2 c^4 [\operatorname{csch}^2 \alpha_2 (1 + \frac{3}{2} \operatorname{csch}^2 \alpha_2)] - \pi \mu_1 c^4 [(\operatorname{csch}^2 \alpha_1 - \operatorname{csch}^2 \alpha_2) (1 + \frac{3}{2} \{\operatorname{csch}^2 \alpha_1 + \operatorname{csch}^2 \alpha_2\})] \right] \quad (7.6)$$

If $\mu_2 = 0$, the section becomes circular with an eccentric hole and

$$\Phi = 2c \sum_{n=1}^{\infty} (-1)^n \left[\frac{e^{-n\alpha_1} \coth \alpha_1 \cosh n(\alpha_1 - \eta) + e^{-n\alpha_2} \coth \alpha_2 \cosh n(\eta - \alpha_2)}{\sinh n(\alpha_1 - \alpha_2)} \right] \sin \frac{n\pi}{2},$$

which is a well known result.

c) Rectangular section

For this section (Fig. 4) the torsion functions and their constants are found to be the following:

$$\varphi_1 = xy + \sum_{n=0}^{\infty} (A_{1n} \sinh \alpha_n y + B_{1n} \cosh \alpha_n y) \sin \alpha_n x, \quad (8.1)$$

$$\varphi_2 = xy + \sum_{n=0}^{\infty} (A_{2n} \sinh \alpha_n y + B_{2n} \cosh \alpha_n y) \sin \alpha_n x, \quad (8.2)$$

where $\alpha_n = \frac{1}{a} (2n+1)\pi/a$.

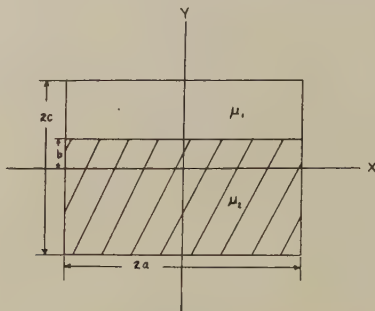


Figure 4

The boundary conditions yield:

$$d_3 B_{2n} = L [\mu_1 \operatorname{sech} \alpha_n c \{ \tanh \alpha_n c - \coth \alpha_n b \} - \mu_2 \{ \tanh \alpha_n c - \coth \alpha_n b \} - (\mu_1 - \mu_2) \operatorname{sech} \alpha_n b \{ \tanh \alpha_n c - \coth \alpha_n b \}], \quad (8.3)$$

$$A_{2n} = B_{2n} \tanh \alpha_n c + L \operatorname{sech} \alpha_n c, \quad (8.4)$$

$$d_4 B_{1n} = L \{ \mu_1 \operatorname{sech} \alpha_n c - (\mu_1 - \mu_2) \operatorname{sech} \alpha_n b \} - \mu_2 \{ A_{2n} + B_{2n} \tanh \alpha_n b \}, \quad (8.5)$$

$$A_{1n} = L \operatorname{sech} \alpha_n c - B_{1n} \tanh \alpha_n c, \quad (8.6)$$

where

$$L = 4a^2 \left(\frac{2}{\pi} \right)^3 \frac{(-1)^{n+1}}{(2n+1)^3},$$

$$d_3 = \mu_1 \{ \tanh \alpha_n b \tanh \alpha_n c - 1 \} - \mu_1 \{ \coth \alpha_n b \tanh \alpha_n c - 1 \} - \mu_1 \tanh \alpha_n c \{ \tanh \alpha_n c - \tanh \alpha_n b \} - \mu_2 \tanh \alpha_n c \{ \tanh \alpha_n c - \coth \alpha_n b \},$$

and

$$d_4 = \mu_1 \{ \tanh \alpha_n c - \tanh \alpha_n b \}.$$

$$D = 2\mu_1 \left\{ \frac{2a^3}{3} (c - b) + \sum_{n=0}^{\infty} \frac{8a^3 (-1)^n}{(2n+1)^4 \pi^4} (A_{1n} [\sinh \alpha_n c - \sinh \alpha_n b] + B_{1n} [\cosh \alpha_n c - \cosh \alpha_n b]) - \sum_{n=0}^{\infty} \frac{2a (-1)^n}{(2n+1) \pi} (A_{1n} [c \cosh \alpha_n c - b \cosh \alpha_n b] \right.$$

$$\begin{aligned}
& + B_{1n} [c \sinh \alpha_n c - b \sinh \alpha_n b] \Big) + 2 \mu_2 \left\{ \frac{2a^3}{3} (b+c) \right. \\
& + \sum_{n=0}^{\infty} \frac{8a^2}{(2n+1)^2} \frac{(-1)^n}{\pi^2} (A_{2n} [\sinh \alpha_n b + \sinh \alpha_n c] + B_{2n} [\cosh \alpha_n b - \cosh \alpha_n c]) \\
& \left. - \sum_{n=0}^{\infty} \frac{2a(-1)^n}{(2n+1)\pi} (A_{2n} [b \cosh \alpha_n b + c \cosh \alpha_n c] + B_{2n} [b \sinh \alpha_n b - c \sinh \alpha_n c]) \right\}.
\end{aligned}$$

If $\mu_1 = \mu_2$, the solution becomes the known solution for an isotropic rectangular section:

$$D = \mu \left\{ \frac{16a^3 c}{3} - \left(\frac{4}{\pi} \right)^5 \sum_{n=0}^{\infty} \frac{\tanh \alpha_n c}{(2n+1)^5} \right\}.$$

COMPOSITE SECTIONS (PART ISOTROPIC AND PART ORTHOTROPIC)

The type of section treated here will in general consist of an outer boundary designated by C_1 and an inner boundary designated by C_2 (Fig. 5). The portion of the section between C_1 and C_2 will be isotropic with shear modulus μ and torsion function Φ . The material inside C_2 will be orthotropic with shear modulus μ_1 in the x -direction, and μ_2 in the y -direction. The torsion function here will be designated as Φ_1 .

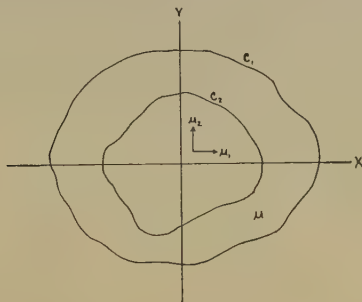


Figure 5

The boundary conditions to be satisfied are:

- $\Phi_1 = 0$ on C_1 .
- Across C_2 , $\Phi = \Phi_1$.
- Across C_2 , $l \tau_{xz} + m \tau_{yz} = (l \tau_{xz} + m \tau_{yz})_1$.

where

$$\nabla^2 \Phi = 0, \quad \mu_1 \frac{\partial \Phi_1}{\partial x^2} + \mu_2 \frac{\partial \Phi_1}{\partial y^2} = 0.$$

1. Completely orthotropic Sections.

For purposes of later comparison and in order to facilitate the formulation of the composite section problems in this section, we will introduce some solutions for completely orthotropic sections.

a) Circular sections of external radius a .

$$\Phi_1 = \frac{\mu_2 - \mu_1}{\mu_1 + \mu_2} xy, \quad (9.1)$$

$$D = \frac{\pi a}{\mu_1 + \mu_2} \mu_1 \mu_2. \quad (9.2)$$

b) Elliptic section with semi-major axis a , and semi-minor axis b .

$$\Phi_1 = \frac{(\mu_1 b^2 - \mu_2 a^2)xy}{\mu_1 b^2 + \mu_2 a^2}, \quad (10.1)$$

$$D = \frac{\pi \mu_1 \mu_2 a^3 b^3}{\mu_1 b^2 + \mu_2 a^2} \quad (10.2)$$

c) Rectangular section (Fig. 6)

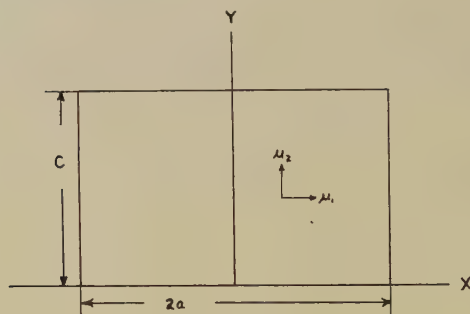


Figure 6

$$\Phi_1 = xy + \sum_{n=0}^{\infty} [A_n \sinh \beta_n y + B_n \cosh \beta_n y] \sin \alpha_n x, \quad \begin{cases} \alpha_n = \frac{1}{2}(2n+1)\pi/a \\ \beta_n = \sqrt{\frac{\mu_1}{\mu_2}} \alpha_n \end{cases} \quad (11.1)$$

The boundary conditions yield:

$$A_n = \sqrt{\frac{\mu_2}{\mu_1}} \frac{4a^2 (2/\pi)^3 (-1)^{n+1}}{(2n+1)^3}, \quad (11.2)$$

$$B_n = \sqrt{\frac{\mu_2}{\mu_1}} \frac{4a^2 (2/\pi)^3 (-1)^{n+1}}{(2n+1)^3} \left\{ \frac{1 - \operatorname{sech} \beta_n c}{\tanh \beta_n c} \right\}. \quad (11.3)$$

$$D = \frac{4a^3 c \mu_2}{3} - \frac{4 \mu_2 a^2}{\pi^2} \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)^2} \{A_n \sinh \beta_n c + B_n \cosh \beta_n c - B_n\} - \frac{2ac \sqrt{\mu_1 \mu_2}}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)^2} \{A_n \cosh \beta_n c + B_n \sinh \beta_n c\}. \quad (11.4)$$

2. Partly isotropic and partly orthotropic sections.

a) Concentric circles.

This type of section is represented in Figure 7.

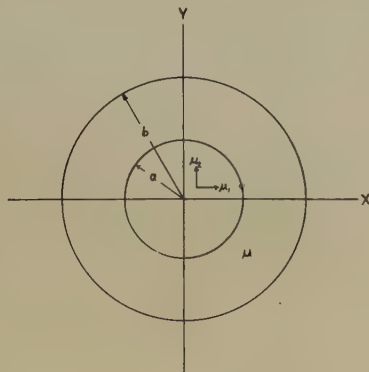


Figure 7

Let us assume:

$$\Phi = (A_1 r + \frac{B_1}{r^2}) \sin 2\theta, \quad (12.1)$$

$$\Phi_1 = A_2 r \sin 2\theta. \quad (12.2)$$

Then

$$2d_5 A_1 = a^4 (\mu_1 - \mu_2) \quad (12.3)$$

$$2d_5 B_1 = a^4 b^4 (\mu_1 - \mu_2) \quad (12.4)$$

$$2d_5 A_2 = (\mu_1 - \mu_2)(b^4 + a^4), \quad (12.5)$$

where

$$d_5 = (b^4 + a^4)(\mu_1 + \mu_2) + 2\mu(b^4 - a^4).$$

For torsional rigidity we obtain:

$$D = \frac{1}{2} \pi \mu (b^4 - a^4) + \frac{1}{2} \frac{\pi a^4}{d_5} [2\mu_1 \mu_2 (b^4 + a^4) + \mu (\mu_1 + \mu_2)(b^4 - a^4)]. \quad (12.6)$$

If $\mu = 0$, the section becomes completely orthotropic and

$$\Phi_1 = \frac{(\mu_1 - \mu_2)}{(\mu_1 + \mu_2)} xy.$$

If $\mu_1 = \mu_2$, the material inside C_2 becomes isotropic and

$$\varphi = 0.$$

These particular cases agree with those obtained previously. It may be noticed that the rigidity corresponding to the outside section is $\frac{1}{2} \pi \mu (b^4 - a^4)$ regardless of whether the inner section is isotropic or anisotropic.

b) Confocal ellipses (Fig. 8)

Again we use the elliptic transformation given in equation 4.1.

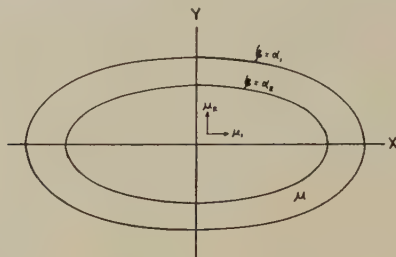


Figure 8

We take φ and φ_1 of the form:

$$\varphi = -(A_1 \sinh 2\eta + B_1 \cosh 2\eta) \sin 2\eta, \quad (13.1)$$

$$\varphi_1 = -A_2 \sinh 2\eta \sin 2\eta. \quad (13.2)$$

The boundary conditions give:

$$4d_6 A_1 = -c^2 \left\{ [(\mu_1 - \mu_2) - (\mu_1 + \mu_2) \cosh 2\alpha_2] [\coth 2\alpha_2 \operatorname{sech} 2\alpha_1] + 2\mu \sinh 2\alpha_2 \operatorname{sech} 2\alpha_1 - [2\mu_1 \sinh^2 \alpha_2 - 2\mu_2 \cosh^2 \alpha_2 + 2\mu] \tanh 2\alpha_1 \right\}, \quad (13.3)$$

$$4d_6 B_1 = c^2 \left\{ [(\mu_1 - \mu_2) - (\mu_1 + \mu_2) \cosh 2\alpha_2 + 2\mu \cosh 2\alpha_2] \operatorname{sech} 2\alpha_1 - 2[\mu_1 \sinh^2 \alpha_2 - \mu_2 \cosh^2 \alpha_2 + \mu] \right\}, \quad (13.4)$$

$$A_2 = \frac{c^2}{4} \operatorname{sech} 2\alpha_1 + B_1 (\coth 2\alpha_2 - \tanh 2\alpha_1), \quad (13.5)$$

where

$$d_6 = [(\mu_1 - \mu_2) - (\mu_1 + \mu_2) \cosh 2\alpha_2] [\tanh 2\alpha_1 - \coth 2\alpha_2] + 2\mu [\cosh 2\alpha_2 \tanh 2\alpha_1 - \sinh 2\alpha_2],$$

$$D = \frac{\pi \mu c^2}{16} [c^2 (\sinh 4\alpha_1 - \sinh 4\alpha_2) - 8A_1 (\sinh 2\alpha_1 - \sinh 2\alpha_2)]$$

$$\begin{aligned}
& -8B_1(\cosh 2\alpha_1 - \cosh 2\alpha_2)] + \frac{\pi}{32} [(\mu_1 + \mu_2)(c^2 \sinh 4\alpha_2 - 8A_2 \sinh 2\alpha_2) \\
& + (\mu_1 - \mu_2)(2c^2 \sinh 2\alpha_2 - 4A_2 \sinh 4\alpha_2)]. \quad (13.6)
\end{aligned}$$

If $\mu_1 = \mu_2$, the material inside C_2 becomes isotropic and the solution reduces to that given in Section A, problem 2a, and if $\mu_1 = \mu_2 = \mu$ the Φ -function reduces to the well known solution for a solid elliptic section.

c) Rectangular section.

The results are obtained for the case where the boundary C_2 corresponds to one of the axes (Fig. 9).

In this case Φ and Φ_1 are taken of the form:

$$\Phi = xy + \sum_{n=0}^{\infty} [A_{1n} \sinh \beta_n y + B_{1n} \cosh \beta_n y] \sin \alpha_n x, \quad (14.1)$$

$$\Phi_2 = xy + \sum_{n=0}^{\infty} [A_{2n} \sinh \alpha_n y + B_{2n} \cosh \alpha_n y] \sin \alpha_n x. \quad (14.2)$$

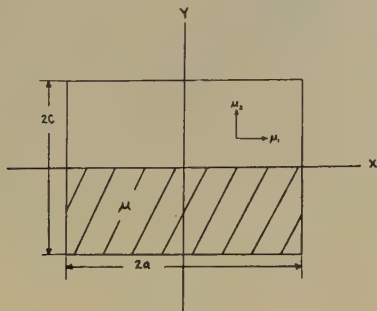


Figure 9

The boundary conditions give:

$$d_7 A_{1n} = L \left[\left\{ \mu (\operatorname{sech} \alpha_n c - 1) + \mu_2 \right\} \tanh \beta_n c + \mu \sqrt{\frac{\mu_2}{\mu_1}} \tanh \alpha_n c \operatorname{csch} \alpha_n c \right], \quad (14.3)$$

$$d_7 A_{2n} = L \left[\left\{ \mu - \mu_2 (1 - \operatorname{sech} \beta_n c) \right\} \tanh \alpha_n c + \sqrt{\mu_1 \mu_2} \tanh \beta_n c \operatorname{csch} \alpha_n c \right], \quad (14.4)$$

$$d_7 B_{1n} = d_7 B_{2n} = L \left[\mu (1 - \operatorname{sech} \alpha_n c) - \mu_2 (1 - \operatorname{sech} \beta_n c) \right], \quad (14.5)$$

where

$$d_7 = \mu \tanh \alpha_n c + \sqrt{\mu_1 \mu_2} \tanh \beta_n c,$$

and

$$\begin{aligned}
L &= \frac{4a^2 (2/\pi)^3 (-1)^{n+1}}{(2n+1)^3} \\
D &= \frac{4a^3}{3} (\mu_e + \mu) + \frac{16\mu_e a^2}{\pi^2} \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)^2} (B_{2n} + A_{2n} \sinh \alpha_n c - B_{2n} \cosh \alpha_n c) \\
&\quad - \frac{4\mu_e c}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)} (A_{2n} \cosh \alpha_n c - B_{2n} \sinh \alpha_n c) \\
&\quad + \frac{16\mu_e a^2}{\pi^2} \sum_{n=0}^{\infty} \frac{(-1)^{n+1}}{(2n+1)^2} (A_{1n} \sinh \beta_n c + B_{1n} \cosh \beta_n c - B_{1n}) \\
&\quad - \frac{4c}{\pi} \sqrt{\frac{\mu_e}{\mu_1}} \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)} (A_{1n} \cosh \beta_n c + B_{1n} \sinh \beta_n c). \tag{14.6}
\end{aligned}$$

For $\mu = 0$, the solution reduces to that for the completely orthotropic rectangular section. If $\mu_1 = \mu_e$, we get the special case of problem 2c, Section A for $b = 0$. If $\mu_1 = \mu_e = \mu$ the solution reduces to that for a solid isotropic rectangular beam.

TABULATION OF TORSIONAL RIGIDITIES

Discrepancies are introduced in the torsional rigidities when we consider composite sections either as completely isotropic or as completely orthotropic sections (Tables 1, 2, and 3). The value of the shear modulus, μ , corresponding to the isotropic section in these tables is taken to be the mean value of the two shear moduli of the particular orthotropic material considered.

Table 1

Comparison of torsional rigidities for berite cylinders of circular section

	$\mu = \frac{\mu_1 + \mu_2}{2} = 207.5$			$\mu = \frac{2\mu_1\mu_2}{\mu_1 + \mu_2} = 172.2$		
a/b	D ₁ /D ₀	D ₂ /D ₀	D ₃ /D ₀	D ₁ /D ₀	D ₂ /D ₀	D ₃ /D ₀
0.10	1.412	0.831	.999	1.700	1.000	1.000
0.20	1.411	0.831	.997	1.699	1.000	1.000
0.50	1.361	0.831	.994	1.640	1.000	1.010
1.00	0.587	0.831	.831	0.707	1.000	1.000

D_0 = Torsional Rigidity for the isotropic case.

a/b = Ratio of the internal radius to the external radius.

D_1 = Torsional rigidity corresponding to equation (3.2).

D_2 = Torsional rigidity corresponding to equation (9.2).

D_3 = Torsional rigidity corresponding to equation (12.6).

$\mu_1 = 293 \times 10^6$ dynes/cm²; $\mu_2 = 122 \times 10^6$ dynes/cm².

Table 2

Comparison of torsional rigidities for sweet gum wood cylinders
of circular section

	$\mu = \frac{\mu_1 + \mu_2}{2} = 141,500$ psi			$\mu = \frac{2\mu_1\mu_2}{\mu_1 + \mu_2} = 137,000$ psi		
a/b	D_1/D_0	D_2/D_0	D_3/D_0	D_1/D_0	D_2/D_0	D_3/D_0
0.10	1.187	.967	1.000	1.227	1.000	1.000
0.20	1.187	.967	1.000	1.227	1.000	1.000
0.50	1.162	.967	0.999	1.202	1.000	1.001
0.80	1.033	.967	0.991	1.070	1.000	1.002
1.00	0.812	.967	0.967	0.840	1.000	1.000

D_0 = Torsional Rigidity for the isotropic case.

a/b = Ratio of the internal radius to the external radius.

D_1 = Torsional rigidity corresponding to equation (3.2).

D_2 = Torsional rigidity corresponding to equation (9.2).

D_3 = Torsional rigidity corresponding to equation (12.6).

$\mu_1 = 168,000$ psi; $\mu_2 = 115,000$ psi.¹

¹ The elastic constants for sweet gum wood as well as those for various other types of wood have been obtained through the courtesy of H. V. March of the Forest Products Laboratory, Madison, Wisconsin.

Table 3

Comparison of torsional rigidities for barite cylinders of elliptic section

		$\mu = \frac{\mu_1 + \mu_2}{2} = 207.5$		$\mu = \frac{2\mu_1\mu_2}{\mu_1 + \mu_2} = 172.2$	
b_1/a_1	a_2/a_1	D_1/D_0	D_2/D_0	D_1/D_0	D_2/D_0
0.10	0.10	1.415	1.380	1.700	1.660
0.10	0.50	1.360	1.380	1.640	1.660
0.10	0.80	1.075	1.380	1.295	1.660
0.10	0.90	0.876	1.380	1.053	1.660
0.10	1.00	0.587	1.380	0.707	1.660
0.50	0.10	1.415	1.152	1.700	1.385
0.80	0.10	1.415	0.912	1.700	1.095
1.00	0.10	1.415	0.831	1.700	1.000

D_0 = Torsional Rigidity of the completely isotropic section.

b_1/a_1 = Ratio of the minor axis to the major axis for external boundaries

b_2/a_2 = Ratio of the major axis of c_2 to the major axis of c_1 .

D_1 = Torsional Rigidity corresponding to equation (3.4).

D_2 = Torsional Rigidity corresponding to equation (10.2).

$\mu_1 = 293$; $\mu_2 = 122$.

BIBLIOGRAPHY

1. Trefftz, E.
1920. Über die Torsion prismatischer Stäbe von polygonalen Querschnitt. Math. Ann. 82, p. 97-112.
2. Seth, B. R.
1934. Torsion of beams of T- and I-cross sections. Proc. Camb. Phil. Soc., 33. p. 392-403.
3. Seth, B. R.
1939. Two dimensional potential problems connected with rectilinear boundaries. Lucknow University Studies No. XIII.
4. Higgins, T. J.
1942. A comprehensive review of Saint-Venant's torsion problem. Amer. Jour. of Physics 10. p. 248-59
5. Muschelisvili, N. I.
1929. Sur le probleme de torsion des cylindres elastiques isotropes. Rendiconti, R. Accademia dei Lincei, 9. p. 295-300.

6. Sokolnikoff, I. S.
1942. Some new methods of solution of two-dimensional problems in elasticity. Bull. Amer. Math. Soc. 48, no. 8. p. 539-55.
7. Prager, W. and J. L. Synge.
1947. Approximations in elasticity based on the concept of function space. Quart. App. Math. 5. p. 241-69.
8. Hay, G. E.
1939. The method of images applied to the problem of torsion. Proc. Math. Soc., London 45, p. 382-97.
9. Muschelisvili, N. I.
1932. Sur le probleme de torsion et de flexion des pontres elastiques compose'es. Bull. de l'academie des sciences de l'U.R.S.S. Ser. VII, no. 7. p. 907-45.
10. Ruchadze, A.
1937. Torsion und Verbiegung durch Querkraefte eines elastischen Balkens, der aus zwei verschiedenen durch Epitrochoiden abgegrenzten Materialien besteht. Travaux de l'institut mathematique de Tbilissi, 1. p. 125-39.

STRESS DISTRIBUTION DUE TO HYDROSTATIC PRESSURE ON A PARABOLIC BOUNDARY¹

KARL LEROY CONRAD

From the Department of Mathematics, Iowa State College

Received August 18, 1949

1. Introduction. The problem of determining the stresses in a semi-infinite body bounded by a plane, known as the "problem of Boussinesq and Cerruti," has been the subject of much research.

Solutions for particular problems have been determined by various methods, e.g. series, reciprocal theorems, and Airy's stress function. The Airy stress function reduces the problem to a biharmonic equation with given boundary conditions.

Kolosoff⁽¹⁾ and Muschelišvili⁽²⁾ probably have been the first to use the complex function theory for the biharmonic problem. Much work has been done in the development of this method. An exposition on this and numerous references have been given by I. S. Sokolnikoff.⁽³⁾ The complex function theory has been applied to the torsion problem by R. C. F. Bertels⁽⁴⁾ and A. C. Stevenson.⁽⁵⁾ The latter has recently used it for a number of boundary value problems pertaining to orthogonal curvilinear boundaries.⁽⁶⁾

Very few solutions exist for the extended Boussinesq problem when the plane boundary is replaced by a surface of finite curvature. It is proposed here to determine the stresses in an infinite solid with a parabolic boundary. An exact solution in closed form has been obtained.

2. Statement of Problem. The problem shall be treated as a two-dimensional one and the infinite body taken as an infinite isotropic cylinder with a parabolic boundary subjected to hydrostatic loading.

The problem consists in determining a biharmonic solution satisfying the following conditions:

- i) The normal stress equals the hydrostatic pressure along the loaded boundary and equals zero over the rest of the parabolic boundary;
- ii) The shearing stress equals zero over the entire boundary;

¹This paper is part of the thesis submitted to the Graduate Faculty of Iowa State College in partial fulfillment of the degree of Master of Science.

iii) All stresses vanish at infinity.

In this problem orthogonal parabolic coordinates are required. A solution in curvilinear coordinates involves transformations of (a) the biharmonic equation, which is not always invariant under transformation like the harmonic equation, (b) the stress components, (c) the boundary conditions. In some cases this is not too difficult and the Airy stress function χ can be inferred from the transformed boundary condition, and the stresses calculated from the transformed equations. Recently Seth⁽⁷⁾ has used essentially this method to discuss bending of plates of rectilinear and elliptic section. However, in general, to determine the stresses in an infinite solid with a curvilinear boundary by this method would be indeed very difficult. In such cases the complex function method is very convenient and has been recently used by a number of workers. For the parabolic boundary using parabolic coordinates the use of the stress function makes the problem almost intractable; therefore, the complex function theory method will be used to solve this problem.

3. Complex Function Method. By the use of the complex function theory the real solution of the biharmonic equation

$$\nabla_1^4 \chi = 16 \frac{\partial^4 \chi}{\partial z \partial \bar{z}} = 0$$

is given by

$$2\chi = z\bar{\phi}(\bar{z}) + \bar{z}\phi(z) + f(z) + \bar{f}(\bar{z}).$$

The important stress relations are

$$\begin{aligned} \tau_{xx} + \tau_{yy} &= 2[\phi'(z) + \bar{\phi}'(\bar{z})], \\ \tau_{xx} - \tau_{yy} + 2i\tau_{xy} &= -2\frac{dz}{d\bar{z}} \frac{d\bar{z}}{dz} [\bar{z}\phi''(\bar{z}) + \bar{f}''(\bar{z})]. \end{aligned}$$

Adding these and changing i to $-i$ gives

$$1) \quad \tau_{xx} - i\tau_{xy} = \bar{\phi}'(\bar{z}) + \phi'(z) - \frac{d\bar{z}}{dz} \frac{dz}{d\bar{z}} [\bar{z}\phi'(z) + f'(z)].$$

Therefore, the stress components can be found in any system of orthogonal curvilinear coordinates when $\phi(z)$ and $f(z)$ are known.

There are certain restrictions on the function χ , namely:

- 1) The stresses must be single-valued,
 11) Unless the region is multiply-connected, as in dislocation problems, the displacements must also be single-valued.

4. Solution of Problem. In parabolic coordinates

$$z = x + iy = \frac{1}{2} \xi^2 = \frac{1}{2} (\xi + i\eta)^2,$$

$$x = \frac{1}{2} (\xi^2 - \eta^2), \quad y = \xi\eta.$$

Thus, the curves $\xi = \text{constant}$ and $\eta = \text{constant}$ represent a system of orthogonal parabolas with common focus at the origin. (see Fig. 1)

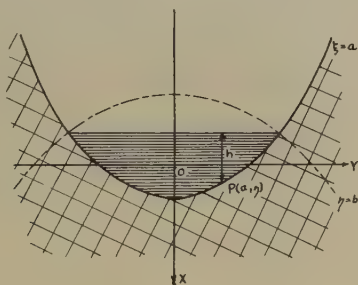


Fig. 1. Cross-section of Semi-infinite Isotropic Cylinder with Parabolic Boundary Stressed by Hydrostatic Pressure -- Parabolic Coordinates.

Using parabolic coordinates the pressure at any point ξ, η on the boundary is

$$p = \frac{\rho g}{2} (b^2 - \eta^2).$$

Therefore, the boundary conditions become

$$\begin{aligned} \text{1) } \tau_{\xi\xi} &= -p = \frac{\rho g}{2} (\eta^2 - b^2) & \text{over } \xi = a, \quad -b < \eta < b, \\ &= 0 & \text{over } \xi = a, \quad |\eta| > b, \\ \text{11) } \tau_{\xi\eta} &= 0 & \text{over } \xi = a, \\ \text{111) } \tau_{\eta\xi} = \tau_{\eta\eta} = \tau_{\xi\eta} &= 0 & \text{as } \xi \rightarrow \infty. \end{aligned}$$

Using the Fourier integral theorem for an even function,

$$F(\eta) = \frac{1}{\pi} \int_0^\infty dv \int_{-\infty}^\infty F(u) \cos v\eta \cos uv \, dv,$$

condition (i) can be written as a single integral.

Now the boundary conditions are

$$\begin{aligned}
 1) \quad \mathcal{F}_{\xi\xi} &= \frac{1}{\pi} \int_0^{\infty} dv \int_{\frac{b^2}{2}}^{\frac{p^2}{2}} (u^2 - b^2) \cos v \cos uv \, dv \\
 2) \quad &= \frac{2p^2}{\pi} \int_a^{\infty} \frac{\cos v (bv \cos bv - \sin bv) dv}{v^3} \quad \text{over } \xi = a, \\
 ii) \quad \mathcal{F}_{\xi\eta} &= 0 \quad \text{over } \xi = a, \\
 iii) \quad \mathcal{F}_{\xi\xi} = \mathcal{F}_{\eta\eta} = \mathcal{F}_{\xi\eta} &= 0 \quad \text{as } \xi \rightarrow \infty.
 \end{aligned}$$

The problem consists, therefore, of finding a biharmonic solution satisfying these conditions. In parabolic coordinates Equation (1) becomes

$$3) \quad \mathcal{F}_{\xi\xi} - i \mathcal{F}_{\xi\eta} = \phi'(z) + \bar{\phi}'(\bar{z}) - \frac{1}{z} \frac{d\phi'(z)}{dz} - \frac{1}{\bar{z}} \frac{d\bar{\phi}'(\bar{z})}{d\bar{z}}.$$

The complex functions $\phi(z)$ and $f(z)$ are chosen of the form

$$\begin{aligned}
 4) \quad \phi(z) &= \int_0^{\frac{\infty}{v}} (1 + v \zeta) e^{-v\zeta} \, dv, \\
 5) \quad f(z) &= \int_0^{\infty} [A_1(1+v\zeta) + A_2 \zeta^2 + A_3 \zeta^3] e^{-v\zeta} \, dv.
 \end{aligned}$$

The quantity $e^{-v\zeta}$ is taken in the integrand of Equation (4) so that the stresses vanish at infinity. The multiplying term $(1+v\zeta)$ is introduced so that $\phi(z) + \bar{\phi}'(\bar{z})$ is real. The integrand in $f(z)$ is taken as an integral polynomial in ζ , multiplied by $e^{-v\zeta}$. It is found that no terms higher than ζ^3 are necessary to obtain an exact solution.

Using these forms of $\phi(z)$ and $f(z)$ in Equation (3) gives

$$\begin{aligned}
 6) \quad \mathcal{F}_{\xi\xi} - i \mathcal{F}_{\xi\eta} &= -4 \int_0^{\infty} \frac{K e^{-v\zeta} \cos v\eta \, dv}{v} - \frac{1}{\zeta} \int_0^{\infty} K e^{-v\zeta} \, dv \\
 &\quad - \frac{1}{\zeta} \int_0^{\infty} [A_1 v^3 + A_2 (v^2 \zeta - 3v) + A_3 (v^2 \zeta^2 - 5v\zeta + 3)] e^{-v\zeta} \, dv.
 \end{aligned}$$

From the boundary conditions (21) and (211)

$$\begin{aligned}
 7) \quad \frac{2p^2}{\pi} \int_0^{\infty} \frac{\cos v\eta (bv \cos bv - \sin bv) dv}{v^3} &= -4 \int_0^{\infty} \frac{K e^{-v\zeta} \cos v\eta \, dv}{v}, \\
 &\quad - \int_0^{\infty} \frac{e^{-v\zeta}}{\zeta^2} \left[\bar{\zeta}_1^2 K + A_1 v^3 + A_2 (v^2 \bar{\zeta}_1 - 3v) + A_3 (v^2 \bar{\zeta}_1^2 - 5v \bar{\zeta}_1 + 3) \right] dv,
 \end{aligned}$$

where $\bar{\zeta}_1 = a + i\eta$, $\bar{\zeta}_1 = a - i\eta$.

From Equation (7) it is evident that

$$8) \quad \frac{-4K e^{-va}}{v} = \frac{2p^2}{\pi} (bv \cos bv - \sin bv),$$

$$9) \quad (a+1\eta)^2 K + A_1 v^3 + A_2 [v^2 (a+1\eta) - 3v] + A_3 [v^2 (a+1\eta)^2 - 5v(a+1\eta) + 3] \sin v\eta = 0.$$

Equations (8) and (9) give

$$K = \frac{\rho g (\sin bv - bv \cos bv)}{2\pi e^{-va} v^2},$$

$$A_3 = -\frac{K}{v^2},$$

$$A_2 = \frac{K}{v^3} (4av - 5),$$

$$A_1 = \frac{K}{v^5} (12av - 4a^2 v^2 - 12).$$

Substituting these values into Equation (6) gives

$$10) \quad \mathcal{F}_{\xi\xi} - i \mathcal{F}_{\xi\eta} = -\frac{2\rho g}{\pi} \int_0^\infty \frac{e^{-v(\xi-a)} \cos v\eta (\sin bv - bv \cos bv) dv}{v^3} + \frac{2\rho g (a\xi + \eta^2) (a-\xi)}{\pi (\xi^2 + \eta^2)} \int_0^\infty \frac{e^{-v(\xi-a)}}{v^3} (\cos v\eta - i \sin v\eta) (\sin bv - bv \cos bv) [(a\xi + \eta^2) + i\eta(a-\xi)] dv.$$

Upon separating the real and imaginary parts Equation (10) yields the desired stresses,

$$11) \quad \mathcal{F}_{\xi\xi} = -\frac{2\rho g}{\pi} \int_0^\infty \frac{e^{-v(\xi-a)} \cos v\eta (\sin bv - bv \cos bv) dv}{v^3} + \frac{2\rho g (a\xi + \eta^2) (a-\xi)}{\pi (\xi^2 + \eta^2)} \int_0^\infty \frac{e^{-v(\xi-a)} \cos v\eta (\sin bv - bv \cos bv) dv}{v^3} + \frac{2\rho g (a-\xi) \eta}{\pi (\xi^2 + \eta^2)} \int_0^\infty \frac{e^{-v(\xi-a)} \sin v\eta (\sin bv - bv \cos bv) dv}{v^3},$$

$$12) \quad \mathcal{F}_{\xi\eta} = -\frac{2\rho g \eta (a-\xi)^2}{\pi (\xi^2 + \eta^2)} \int_0^\infty \frac{e^{-v(\xi-a)} \cos v\eta (\sin bv - bv \cos bv) dv}{v^3} + \frac{2\rho g (a\xi + \eta^2) (a-\xi)}{\pi (\xi^2 + \eta^2)} \int_0^\infty \frac{e^{-v(\xi-a)} \sin v\eta (\sin bv - bv \cos bv) dv}{v^3}.$$

Since

$$\mathcal{F}_{\xi\xi} + \mathcal{F}_{\eta\eta} = 2[\phi'(z) + \bar{\phi}'(\bar{z})] = -\frac{4\rho g}{\pi} \int_0^\infty \frac{e^{-v(\xi-a)} \cos v\eta (\sin bv - bv \cos bv) dv}{v^3}$$

$$13) \quad \mathcal{F}_{\eta\eta} = -\frac{2\rho g}{\pi} \int_0^\infty \frac{e^{-v(\xi-a)} \cos v\eta (\sin bv - bv \cos bv) dv}{v^3}$$

$$\begin{aligned}
& - \frac{2P_E(a\xi + \eta^2)(a-\xi)}{\pi(\xi^2 + \eta^2)} \int_a^\infty \frac{e^{-v(\xi-a)} \cos v\eta (\sin bv - bv \cos bv) dv}{v^2} \\
& - \frac{2P_E(a-\xi)\eta}{\pi(\xi^2 + \eta^2)} \int_a^\infty \frac{e^{-v(\xi-a)} \sin v\eta (\sin bv - bv \cos bv) dv}{v^2} .
\end{aligned}$$

Upon integrating the integrals, the stresses become

$$\begin{aligned}
14) \quad \gamma_{\xi} \frac{\pi}{2P_E} &= \left\{ - \left[\frac{b^2 - \eta^2}{4} + \frac{(\xi-a)^2}{4} \right] \left[\tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right] \right. \\
&\quad + \frac{b(\xi-a)}{2} \left. \right\} + \left\{ \frac{\eta(\xi-a)}{2} \left[\frac{(\xi-a)^2}{\xi^2 + \eta^2} - \frac{(a\xi + \eta^2)}{\eta^2} + 1 \right] \right. \\
&\quad \left. \log \frac{(\xi-a)^2 + (b-\eta)^2}{(\xi-a)^2 + (b+\eta)^2} \right\} \\
&\quad + \frac{(a\xi + \eta^2)(\xi-a)}{\xi^2 + \eta^2} \left\{ \frac{\xi-a}{2} \left[\tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right] - b \right\} \\
&\quad + \frac{\eta^2(\xi-a)^2}{\xi^2 + \eta^2} \left\{ \tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right\} , \\
15) \quad \gamma_{\eta} \frac{\pi}{2P_E} &= \frac{\eta(\xi-a)^2}{\xi^2 + \eta^2} \left\{ \frac{\xi-a}{2} \left[\tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right] - b \right\} \\
&\quad - \left\{ \frac{(\xi-a)^2(a\xi + 2\eta^2)}{4(\xi^2 + \eta^2)} \log \frac{(\xi-a)^2 + (b-\eta)^2}{(\xi-a)^2 + (b+\eta)^2} \right\} \\
&\quad - \left\{ \frac{(a\xi + \eta^2)(\xi-a)}{2(\xi^2 + \eta^2)} \left[\tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right] \right\} , \\
16) \quad \gamma_{\eta} \frac{\pi}{2P_E} &= \left\{ - \left[\frac{b^2 - \eta^2}{4} + \frac{(\xi-a)^2}{4} \right] \left[\tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right] \right. \\
&\quad + \frac{b(\xi-a)}{2} \left. \right\} + \left\{ \frac{\eta(\xi-a)}{2} \left[\frac{(a\xi + \eta^2)}{\xi^2 + \eta^2} - \frac{(\xi-a)^2}{\eta^2} + 1 \right] \right. \\
&\quad \left. \log \frac{(\xi-a)^2 + (b-\eta)^2}{(\xi-a)^2 + (b+\eta)^2} \right\} \\
&\quad + \frac{(a\xi + \eta^2)(\xi-a)}{\xi^2 + \eta^2} \left\{ b - \frac{\xi-a}{2} \left[\tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right] \right\} \\
&\quad - \frac{\eta^2(\xi-a)^2}{2(\xi^2 + \eta^2)} \left\{ \tan^{-1} \frac{b+\eta}{\xi-a} + \tan^{-1} \frac{b-\eta}{\xi-a} \right\} .
\end{aligned}$$

It is of interest to examine the stress distribution along the line

$\eta = 0$ or, in other words, directly below the vertex of the parabolic

boundary. To do this a concrete example is taken: maximum depth of liquid, 200 feet; maximum width, 600 feet. Therefore, $a = 15$ and $b = 20$.

For this special case

$$\mathcal{F}_x \frac{\pi}{2Pg} = [-200 + (\xi-15)^2 (\frac{30-\xi}{2\xi})] [\tan^{-1} \frac{20}{\xi-15}] - 20(\xi-15)(\frac{30-\xi}{2\xi}),$$

$$\mathcal{F}_y = 0,$$

$$\mathcal{F}_y \frac{\pi}{2Pg} = [-200 - (\xi-15)^2 (\frac{30+\xi}{2\xi})] [\tan^{-1} \frac{20}{\xi-15}] + 20(\xi-15)(\frac{30+\xi}{2\xi}),$$

which shows the stresses to be principal stresses along $\eta = 0$.

Table 1 shows the calculated values for $\mathcal{F}_x \frac{\pi}{2Pg}$, $\mathcal{F}_y \frac{\pi}{2Pg}$, and $(\mathcal{F}_x - \mathcal{F}_y) \frac{\pi}{2Pg}$. Fig. 2 gives the graphical representation of the stress distribution for this special case.

TABLE 1

Stress Distribution of Stresses Along Line $\eta = 0$
For Parabola With $a = 15$ and $b = 20$

ξ	$\mathcal{F}_x \pi / 2Pg$	$\mathcal{F}_y \pi / 2Pg$	$(\mathcal{F}_x - \mathcal{F}_y) \pi / 2Pg$
15	-314.2	-314.2	0.0
20	-281.2	-178.5	102.7
25	-230.3	-122.8	107.5
30	-185.0	-97.0	88.0
35	-151.4	-76.6	74.8
40	-124.9	-66.5	58.4
45	-105.8	-57.7	48.1
50	-91.2	-53.0	38.2
60	-69.6	-40.6	29.0
70	-55.6	-38.3	17.3
80	-47.1	-33.4	13.7
100	-29.0	-25.0	4.0

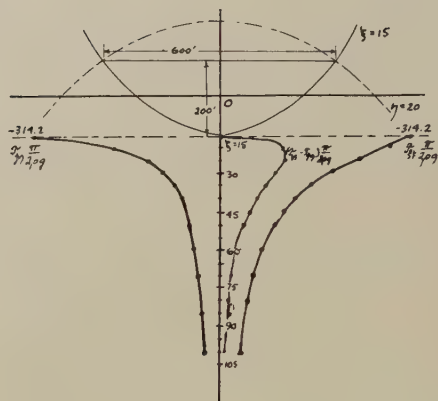


Fig. 2. Stress Distribution Along Line $\eta = 0$ for Parabola with $a = 15$, $b = 20$.

Bibliography

1. Kolosoff, G. V. Über einige Eigenschaften des ebenen Problems der Elastizitätstheorie. Zeitschrift für Mathematik und Physik. 62:383-409. 1914.
2. Muschelishvili, N. I. Sur l'intégration de l'équation biharmonique. Bulletin de l'Académie des Sciences de l'URSS. Series 6, 13:663-686. 1919.
- Praktische Lösung der fundamentalen Randwertaufgaben der Elastizitätstheorie in der Ebene für einige Perandungsformen. Zeitschrift für angewandte Mathematik und Mechanik. 13:264-282. 1933.
3. Sokolnikoff, I. S. Some new methods of solution of two-dimensional problems in elasticity. Bulletin of the American Mathematical Society. 48:539-555. 1942.
4. Bartels, R. C. F. Torsion of hollow cylinders. Transactions of the American Mathematical Society. 53:1-13. 1943.
5. Stevenson, A. C. The Dirichlet problem for a ring space. Philosophical Magazine. Series 7, 39:297-303. 1948.
6. ----- Complex potentials in two-dimensional elasticity. Proceedings of the Royal Society of London. Series A. 184:129-179. 1945.
7. Seth, B. R. Bending of clamped rectilinear plates. Philosophical Magazine, Series 7, 38:292-297. 1947.
- Bending of an elliptic plate with a confocal hole. Quarterly Journal of Mechanics and Applied Mathematics. 2:177-181. 1949.

AUTHOR INDEX

- Anderson, J. P., 137
 Atkins, Richard Elton, 3
- Banzon, Julian, 219
 Barger, Gerald L., 4
 Beach, James W., 7
 Beck, S. D., 249
 Becker, Elery R., 189, 237, 323
 Benkeser, Robert Anthony, 11
 Bever, Robert J., 289, 297
 Bhaumik, Hari Das, 13
 Broadbent, Francis E., 16
 Brodine, Charles E., 237, 323
 Brouns, Richard J., 18
 Brown, Horace D., 20
 Byrd, Dorwin A., 323
- Carlin, Mary Agnes Frances, 23
 Clappison, Bonnie L., 237
 Cleary, Robert E., 195
 Clegg, Robert Edward, 25
 Conrad, Karl Leroy, 397
 Crouthamel, Carl E., 289
- Diehl, Harvey, 273, 279, 289, 297
 Duke, Frederick R., 297
- Emery, Willis Lauerns, 27
 English, Thomas S., 317
 Erickson, Ray Charles, 30
- Frey, Kenneth John, 33
 Fulmer, E. I., 219
- Gilman, J. C. 261
 Goss, R. N., 375
- Harrison, Dorothy Lucile, 36
 Hehn, Erhardt R., 39
 Henn, Johanna, 273
 Hollowell, Eugene Graham, 41
 Hutton, Curtis Evan, 44
- Isely, Duane, 125
- Keller, Kenneth R., 46
 Khambanonda, Ian, 48
- Langenhoo, Carl Eric, 50
 Lewis, William M., 209, 317, 355
 Lilly, J. H., 249
- Maloney, Clifford Joseph, 53
 Marousek, Alice A. 323
 Mathews, John, Jr., 279
 Morris, Harold Donald, 55
- Nobis, John Francis, 57
- Paretsky, David, 61
 Payne, L. E., 381
 Picken, Joseph C., Jr., 64
 Plunkett, Mary Alys, 67
 Provost, Maurice W., 69
 Prudent, Inez, 72
- Rossmann, Elmer C., 75
- Sass, John E., 301
 Scoggin, John K., 363
 Sharp, Silas S., 78
 Sigler, William F., 103, 311
 Sprague, G. F., 301
 Stanford, George, 80
 Starrett, William Charles, 83
- Tate, William Harold, 343
 Tauber, Oscar E., 363
 Thomas, Robert O., 86
- Underkofler, L. A., 219
- Vinograde, B., 101
- Weber, Charles Robert, 89
 White, Alan G. C., 91
 Wimmer, Ernest L., 94
- Young, Roy A., 97

SUBJECT INDEX

- Abnormalities, in maize, "accessory blade" and, 301
 "Accessory blade," in maize, and associated abnormalities, 301
 Agronomic characters, in barley, the inheritance of, 39
 Alanine, bacterial metabolism of, 61
 Alaska, flora of, VII, 137
 Alcohol, furfuryl, production and some reactions of, 20
 Algebras, commutative, note on an invariant of, 101
 Azobenzene, toxicity to insects of, 78
- Barium sulfate, rate of precipitation of, 297
 Barley, the inheritance of agronomic characters in, 39
 Bass
 smallmouth black, in some Iowa streams, growth and food habit studies of, 343
 white in Storm Lake, Iowa, life history of, 311
 Beef
 collagen and elastin content of four muscles of, 72

- histological, physical, and organoleptic changes in three grades of, 36
- Bullhead, northern black, *Ameiurus m. melas* (Rafinesque), use of vertebrae as indicators of the age of, 209
- Cadmium, separation from zinc by controlled cathode potential electrodeposition of, 18
- Canada, flora of parts adjacent to Alaska, VII, 137
- Canvas-back, *Nyroca valisineria* (Wilson), in southeastern Oregon, life history and ecology of, 30
- Capsicum frutescens* L., polygenic inheritance of fruit size in, 48
- Cassava, fermentative utilization of, 219
- Charlara quercina*, host-parasite relationship of, 97
- Chaenobryttus coronarius* (Bartram), in Red Haw Hill Reservoir, Iowa, 317
- Chloromethyl ether, of 2,3-butanediol monoacetate, preparation and reactions of, 94
- Clear Lake, Iowa, life history and management of yellow pikeperch, *Stizostedion v. vitreum* (Mitchill) of, 195
- Clovers, common, seed characters of, 125
- Cobalt compounds, oxygen-carrying, presence of water in, 273
- Collagen, in four beef muscles, content of, 72
- Composite sections, torsion of, 381
- Corn borer, European, report on resistance investigations on, 249
- Cover-water interspersed in marshes of Clay and Palo Alto Counties, Iowa, avian responses to, 69
- Cylinders, slowly rotating eccentric, flow of viscous fluid between, 7
- Decomposition, of organic matter in soils, some factors affecting, 16
- Dermestes maculatus* Deg., oviposition, longevity, period of incubation, the bionomics of, 363
- Dibenzothiophenes, substituted, orientation and cleavage of, 57
- Drought hazard, in Iowa, characterization and evaluation of, 4
- Duck plasma, normal and immune, on chick infections of *plasmodium lophurae* induced with parasites in duck erythrocytes, influence of, 323
- Elastin, in four beef muscles, content of, 72
- Electric discharges in gases, radio-frequency radiation from, 27
- Electrodeposition, controlled cathode potential, separation of cadmium from zinc by, 18
- Ethanol, production of, 219
- Ether, chloromethyl, of 2,3-butanediol monoacetate, preparation and reactions of, 94
- Ferrous iron, with noxime, reaction of, 279
- Flora of Alaska, and adjacent areas, VII, 137
- Freezing, effect on tenderness and on ice crystal formation in poultry after various periods of aging of, 23
- Fungi, parasitic, from Iowa, second supplementary list of, 261
- Furfuryl alcohol, production and some reactions of, 20
- Glycine, bacterial metabolism of, 61
- Glycine max* \times *G. ussuriensis*, inheritance and interrelation of some agronomic and chemical characters in an interspecific cross of, 89
- Histological changes in three grades of beef during aging, 36
- Hybrid oat populations, evaluation of certain agronomic and disease characters in, 3
- Hybrids, maize, inheritance of protein, zein, tryptophan, valine, leucine, and isoleucine in, 33
- Hydrostatic pressure, on a parabolic boundary, stress distribution due to, 397
- Integral equations, whose iterates satisfy linear relations, properties of, 50
- Isoleucine, in two maize hybrids, inheritance of, 33
- Kidney tissue dihydroxyphenylalanine metabolism by, 25
- Legumes, in culture solutions, effect of soluble manganese on growth of, 55
- Leucine, in two maize hybrids, inheritance of, 33
- Limnology, and vegetation, in two artificial lakes in southern Iowa, fisheries investigation of, 355
- Linear relations, properties of kernels of integral equations whose iterates satisfy, 50
- Loess, Peorian, morphology and genesis of prairie soils developed from, 44
- Longevity, *Dermestes maculatus* Deg., bionomics of, 363
- Maize
 histological development of "accessory blade" and associated abnormalities of, 301
 hybrids, inheritance of protein, zein, tryptophan, valine, leucine, and isoleucine in, 33

- Maize (*continued*)
 inbred and hybrid seed, when subjected to freezing temperatures, viability and vigor of, 75
 inbred lines, comparison involving the numbers of and relationship between testers in evaluating of, 46
 photoperiodic responses of, 86
 Manganese, soluble, affect on growth of various legumes in culture solutions and in acid soils by, 55
 Metabolism
 bacterial, of glycine and alanine, 61
 dihydroxyphenylalanine, by kidney tissue, 25
 fat, in yeast, 91
 Microbiological activity and soil moisture tension, 13
 Minnows, of Des Moines River, Boone County, Iowa, ecological study of, 83
 Moisture tension, soil, and microbiological activity, 13
 Nioxime, reaction of ferrous iron with, 279
 Nitrogen transformations, and organic matter decomposition in soils, some factors affecting, 16
Nyroca valisineria (Wilson), canvasback, in southeastern Oregon, life history and ecology of, 30
 Oat populations, bulk hybrid, evaluation of certain agronomic and disease characters in advanced generations of, 3
 Organoleptic changes in three grades of beef during aging, 36
 Organosilicon compounds, some substitution reactions of, 11
 Oviposition, *Dermestes maculatus* Deg., bionomics of, 363
 Oxygen-carrying cobalt compounds, presence of water in, 273
 Parabolic boundary, stress distribution due to hydrostatic pressure on, 397
 Parasitic fungi, of Iowa, second supplementary list of, 261
 Pepper, red, (*Capsicum frutescens* L.) polygenic inheritance of fruit size in, 48
 Pikeperch, *Stizostedion v. vitreum* (Mitchill), of Clear Lake, Iowa, life history and management of, 195
Plasmodium lophurae
 in White Pekin ducks, post-crisis in blood-induced infections of, 237
 induced with parasites in duck erythrocytes, influence of normal and immune duck plasmas on chick infections of, 323
 in White Pekin ducks, report on thirty-five drugs and three plant materials tested against, 189
 Poultry, effect of freezing on tenderness and on ice crystal formation after various periods of aging in, 23
 Precipitation, of barium sulfate, rate of, 297
 Pressure, hydrostatic, on a parabolic boundary, stress distribution due to, 397
 Protein, in two maize hybrids, inheritance of, 33
 Quercus, host-parasite relationship of *Chalara quercina* and, 97
 Radiation, radio-frequency, from electric discharges in gases, 27
 Red Haw Hill Reservoir, Iowa, warmouth, *Chaenobrytus coronarius* (Bartram) of, 317
 Seed, inbred and hybrid maize, when subjected to freezing temperatures, viability and vigor of, 75
 Soils
 acid, effect of soluble managanese on growth of various legumes in, 55
 some factors affecting nitrogen transformations and organic matter decomposition in, 16
 potassium fixation as affected by type of clay mineral, moisture conditions, and concentration of other ions in, 80
 prairie, developed from Peorian loess in southwestern Iowa, morphology and genesis of, 44
 Soybean oil, commercial extraction of, using non-inflammable solvents, 41
 Soybeans, *Glycine max* × *G. ussuriensis*, inheritance and interrelation of some agronomic and chemical characters in interspecific cross in, 89
 Spirit Lake, Dickinson County, aquatic and shore vegetation of, 103
 Stizostedion v. vitreum (Mitchill), of Clear Lake, Iowa, life history and management of, 195
 Storm Lake, Iowa, life history of white bass of, 311
 Sulfides, substituted pyridine and quino-line, 67
 Survey sampling, stratification in, 53
 Testers, in evaluating inbred lines of maize, comparison involving the numbers of and relationship between, 46
 Thiamine, dependent systems, physiological action of thiamine analogues in, 64
 Titration apparatus, improved high frequency conductimetric, 289
 Triangular section, center of flexure of beams of, 375
Trifolium, seed characters of, 125
 Tryptophan, in two maize hybrids, inheritance of, 33

- Valine, in two maize hybrids, inheritance of, 33
- Viscous fluid, between slowly rotating eccentric cylinders, flow of, 7
- Warmouth, *Chaenobryttus coronarius* (Bartram) in Red Haw Hill Reservoir, Iowa, 317
- White Pekin ducks
post-crisis in blood-induced *plasmodium lophurae* infections in, 237
report on thirty-five drugs and three plant materials tested against *plasmodium lophurae* in, 189
- Yeast, fat metabolism in, 91
- Zein, inheritance in two maize hybrids of, 33
- Zinc, separation of cadmium by controlled cathode potential electrodeposition of, 18

